

INSTRUCTORS MANUAL SECTION B

B1 Motion in One Dimension.....	7
B1-RT01: Strobe Photographs of Spheres—Displacement I.....	7
B1-RT02: Strobe Photographs of Spheres—Displacement II.....	8
B1-RT03: Strobe Photographs of Spheres—Average Velocity I.....	9
B1-RT04: Strobe Photographs of Spheres—Average Velocity II.....	10
B1-RT05: Ball Strobe Diagrams—Average Velocity.....	11
B1-RT06: Ball Strobe Diagrams—Acceleration.....	12
B1-RT07: Ball Strobe Diagrams—Acceleration.....	13
B1-RT08: Ball Strobe Diagrams—Speed.....	14
B1-CRT09: Velocity-Time Graphs—Speed-Time Graphs.....	15
B1-CRT10: Velocity-Time Graph—Speed-Time Graphs.....	16
B1-WWT11: Speed-Time Graphs of Two Objects—Displacement.....	17
B1-WWT12: Ball Thrown Upward and Comes Back Down—Speed-Time Graph.....	18
B1-RT13: Position-Time Graphs—Displacement.....	19
B1-RT14: Position-Time Graphs—Average Speed.....	20
B1-RT15: Vertical Model Rockets—Maximum Height.....	21
B1-RT16: Cars—Change of Velocity.....	22
B1-WWT17: Velocity-Time Graph—Acceleration-Time Graph.....	23
B1-CT18: Velocity-Time Graphs—Displacement.....	24
B1-WWT19: Acceleration-Time Graph—Velocity-Time Graph.....	25
B1-WWT20: Velocity-Time Graph—Acceleration-Time Graph.....	26
B1-CRT21: Acceleration-Time Graph—Velocity-Time Graph.....	27
B1-CT22: Velocity-Time Graphs of Objects—Displacement.....	28
B1-RT23: Velocity-Time Graphs—Displacement.....	29
B1-WWT24: Ball Thrown Upward and Comes Back Down—Velocity-Time Graph.....	30
B1-SCT25: Ball Thrown Upward—Graph of Speed-Time.....	31
B1-WWT26: Velocity-Time Graph of Two Objects—Fastest Object.....	32
B1-CRT27: Traveling Students—Velocity-Time Graph.....	33
B1-WWT28: Position-Time Graph of Two Objects—Fastest Object.....	34
B1-RT29: Velocity-Time Graphs—Distance Traveled.....	35
B1-SCT30: Velocity-Time Graphs of Objects—Displacement.....	36
B1-QRT31: Position or Velocity Graphs—Change Direction.....	37
B1-WWT32: Ball Thrown Straight Upward—Time to Reach Top.....	38
B1-QRT33: Position-Time Graph—Direction.....	39
B1-QRT34: Velocity-Time Graph—Direction.....	40
B1-QRT35: Position-Time Graphs of Children—Kinematic Quantities.....	41
B1-QRT36: Velocity-Time Graphs of Children—Kinematic Quantities.....	42
B1-WBT37: Position Equation—Physical Situation.....	43
B1-QRT38: Position or Velocity Graphs—Change Direction.....	44
B1-SCT39: Bicyclist on a Straight Road—Average Speed.....	45
B1-QRT40: Position Equations—Motion Characteristics.....	46
B1-WWT41: Acceleration-Time Graph—Interpretation.....	47
B1-RT42: Velocity-Time Graphs—Instantaneous Velocity.....	48
B1-RT43: Velocity-Time Graphs—Acceleration.....	49
B1-RT44: Position-Time Graphs—Instantaneous Speed.....	50
B1-RT45: Position-Time Graphs—Instantaneous Velocity.....	51
B1-WWT46: Ball Thrown Straight Upward—Time to Reach Top.....	52
B1-QRT47: Position, Velocity, and Acceleration Signs—Position, Direction, and Rate.....	53
B1-WWT48: Velocity-Time Graphs—Acceleration.....	54
B1-QRT49: Position, Velocity, and Acceleration Signs—Position, Direction, and Rate.....	55
B1-WWT50: Bicyclist on a Hill—Velocity-Time Graph.....	56
B1-QRT51: Velocity-Time Graphs—Direction.....	57
B1-RT52: Velocity-Time Graphs—Displacement.....	58
B1-WWT53: Walking Round Trip—Average Speed.....	59

B1-RT54: Velocity-Time Graphs—Acceleration.....	60
B1-WWT55: Round Trip up a Mountain—Average Speed.....	61
B1-QRT56: Position-Time Graphs—Acceleration and Velocity.....	62
B1-RT57: People on Trains—Speed Relative to Ground.....	63
B1-QRT58: Moving Asteroids near Spaceship—Velocity Direction.....	64
B2 Motion in Two Dimensions.....	65
B2-CT01: Motorcycle Trips—Displacement.....	65
B2-SCT02: Motorcycle Trips—Displacement.....	66
B2-RT03: Students’ Journeys—Average Velocity.....	67
B2-SCT04: Car on a Country Road—Average Speed and Velocity.....	68
B2-QRT05: Velocity and Position of the Moon—Velocity Change Direction.....	69
B2-SCT06: Motorcycle on Road Course—Acceleration.....	70
B2-WWT07: Speedboats Changing Velocities—Acceleration.....	71
B2-WWT08: Falling Rock and Thrown Rock—Velocity-Time Graphs.....	72
B2-QRT09: Projectile Motion—Velocity-Time and Acceleration-Time Graphs.....	73
B2-QRT10: Projectile Motion for Two Rocks—Velocity-Time and Acceleration-Time Graphs.....	74
B2-QRT11: Baseball Projectile Motion—Velocity-Time and Acceleration-Time Graphs.....	75
B2-CRT12: Projectile Motion for Two Rocks—Velocity-Time Graphs.....	76
B2-CRT13: Projectile Motion for Two Rocks—Acceleration-Time Graphs.....	77
B2-LMCT14: Dropped Practice Bomb—Horizontal Distance Traveled.....	78
B2-RT15: Rifle Shots—Time to Hit Ground.....	79
B2-RT16: Arrows—Maximum Heights.....	80
B2-RT17: Model Rockets Fired at an Angle—Horizontal Speed at Top.....	81
B2-RT18: Cannonballs—Acceleration at the Top.....	82
B2-RT19: Cannonballs—Horizontal Distance.....	83
B2-WWT20: Horizontally Launched Toy Trucks—Time in Air I.....	84
B2-RT21: Cannonballs—Time in Air.....	85
B2-WWT22: Horizontally Launched Toy Trucks—Time in Air II.....	86
B2-CT23: Toy Trucks Rolling from Tables with Different Heights—Time.....	87
B2-CT24: Toy Trucks with Different Speeds Rolling from Identical Tables—Time.....	88
B2-CT25: Projectile Motion for Two Rocks—Velocity and Acceleration.....	89
B2-QRT26: Constant Speed Car on Oval Track—Acceleration and Velocity Directions.....	90
B2-QRT27: Car on Oval Track—Direction of the Acceleration and Velocity.....	91
B3 Newton’s Laws.....	92
B3-RT01: Packages Moving on a Conveyor Belt—Net Force.....	92
B3-RT02: Water Skiers—Net Force.....	93
B3-RT03: Stacked Packages Moving on Moving Conveyor Belt—Net Force.....	94
B3-RT04: Moving Car with Boat Trailer—Net Force on Boat Trailer.....	95
B3-RT05: Moving Spaceship with Four Cargo Pods—Tension in Rods.....	96
B3-RT06: Carts on Inclines—Net Force.....	97
B3-RT07: Two Stacked Blocks at Rest—Net Force on the Bottom Block.....	98
B3-RT08: Force Pushing Box—Acceleration.....	99
B3-CT09: Blocks in Moving Elevators—Stretch of Spring.....	100
B3-RT10: Two-Dimensional Forces on a Treasure Chest—Final Speed.....	101
B3-RT11: Arrows—Acceleration.....	102
B3-RT12: Rocks Thrown Upward—Net Force.....	103
B3-RT13: Rocks Thrown Downward—Net Force.....	104
B3-RT14: Rocks Thrown Downward—Acceleration.....	105
B3-RT15: Blocks Attached to Fixed Objects—Rope Tension.....	106
B3-RT16: Blocks Attached to Wall—Rope Tension.....	107
B3-RT17: Hanging Weights—Rope Tension.....	108
B3-RT18: Blocks and Weights at Rest—Tension.....	109
B3-QRT19: Ball Strobe Motion—Net Force.....	110
B3-RT20: Net Force-Acceleration Graphs—Mass.....	111
B3-RT21: Ropes Pulling Boxes—Acceleration.....	112

B3-RT22: Ropes Pulling Boxes—Rope Tension.....	113
B3-RT23: Tugboat Pushing Barges—Force Tugboat Exerts on Lead Barge.....	114
B3-RT24: Tugboat Pushing Barges—Force Tugboat Exerts on First Barge.....	115
B3-RT25: Forces on Blocks on Smooth Surfaces—Speed.....	116
B3-CT26: Curler Pushing Stone—Force on Stone.....	117
B3-RT27: Ropes Pulling Identical Boxes—Rope Tension.....	118
B3-QRT28: Student Pushing Two Blocks—Force.....	119
B3-RT29: Ropes Pulling Identical Boxes—Rope Tension.....	120
B3-RT30: Forces on Objects on Rough Surfaces—Velocity Change.....	121
B3-QRT31: Skateboard Rider Coasting Down a Hill—Acceleration and Net Force.....	122
B3-CT32: Ropes Pulling Boxes—Rope Tension.....	123
B3-WWT33: Lifting up a Pail—Strategy.....	124
B3-WWT34: Velocity-Time Graphs—Net Force.....	125
B3-CT35: Blocks Moving at Constant Speed—Force on Block.....	126
B3-WWT36: Pulling a Block across a Rough Surface—Force Relationships.....	127
B3-CRT37: Velocity-Time Graph—Force-Time Graph.....	128
B3-RT38: Stacked Blocks Speeding up on a Conveyor Belt—Net Force.....	129
B3-CT39: Spaceships Pulling Two Cargo Pods—Tension in Tow Rods.....	130
B3-QRT40: Three Vectors—Resultant.....	131
B3-CT41: Spaceships Pulling Two Cargo Pods—Tension or Compression in Tow Rods.....	132
B3-QRT42: Thrown Baseball—Free-Body Diagram at the Top.....	133
B3-WWT43: Box on Incline—Forces.....	134
B3-WWT44: Thrown Baseball—Free-Body Diagram for Ascending Baseball.....	135
B3-CRT45: Suitcase Sliding Down Ramp at Constant Speed—Forces on Suitcase.....	136
B3-RT46: Two Blocks at Rest—Force Difference.....	137
B3-RT47: Two Stacked Blocks at Rest—Force on the Top Block by Bottom Block.....	138
B3-RT48: Two Stacked Blocks at Rest—Force on the Top Block by the table.....	139
B3-RT49: Two Stacked Blocks at Rest—Force on the Bottom Block by Table.....	140
B3-RT50: Accelerating Car and Boat Trailer—Force Difference.....	141
B3-RT51: Car and Boat Trailer on an Incline—Force Difference.....	142
B3-CT52: Identical Toy Truck Collisions—Force and Acceleration.....	143
B3-CT53: Toy Truck Collisions—Force on Trucks.....	144
B3-CT54: Toy Truck Collisions—Acceleration.....	145
B3-WWT55: Tennis Ball and Racquet—Force.....	146
B3-WWT56: Ball Hitting a Wall—Forces.....	147
B3-WWT57: Potato on Table—Forces and Reaction Forces.....	148
B3-LMCT58: Identical Toy Trucks Colliding Head-on—Force on Trucks.....	149
B3-CT59: Person in an Elevator Moving Upward—Scale Reading.....	150
B3-RT60: Person in a Moving Elevator—Scale Reading.....	151
B3-RT61: Person in an Elevator Moving Downward—Scale Reading.....	152
B3-CT62: Person in an Elevator—Scale Reading.....	153
B3-QRT63: Person in an Elevator—Scale Reading.....	154
B3-CT64: Person in an Elevator Moving Downward—Scale Reading.....	155
B3-CT65: Block Held on Smooth Ramp—Weight and Normal Force.....	156
B3-WWT66: Two Blocks at Rest—Normal Force.....	157
B3-RT67: Boxes on Rough Vertical Surface—Normal Force on Wall.....	158
B3-QRT68: Stacked Blocks—Normal Forces.....	159
B3-WWT69: Blocks on a Rough Incline—Tension.....	160
B3-SCT70: Hanging Stone Connected to Box—Free-Body Diagrams.....	161
B3-RT71: Water Skiers—Tension.....	162
B3-RT72: Hanging Blocks—Tension.....	163
B3-CT73: Pulling a Crate Across Floor—Applied Force.....	164
B3-RT74: Hanging Stone Connected to Box on Rough Surface—Acceleration.....	165
B3-RT75: Moving String Passing over a Pulley—Tension at Points.....	166
B3-SCT76: String at Angle Passing over a Pulley—Tension at Points.....	167
B3-CT77: Ball Suspended from Ceiling by Two Strings—Tension.....	168

B3-SCT78: Hanging Mass—Tension in Three Strings	169
B3-SCT79: Two Connected Objects Accelerating Downward—Tension.....	170
B3-WWT80: Blocks on a Smooth Incline—Tension	171
B3-RT81: Hanging Mass—String Tension.....	172
B3-WBT82: Newton’s Second Law Equation—Physical Situation	173
B3-SCT83: Blocks on a Smooth Incline—Tension	174
B3-CT84: Blocks Moving at Constant Speed—Tension in Connecting String.....	175
B3-LMCT85: Two Connected Objects Accelerating Downward—Tension in String	176
B3-SCT86: Box Pulled on Rough, Horizontal Surface—Frictional Force on Box	177
B3-CT87: Box Moving over Horizontal Surface—Frictional Force on Box.....	178
B3-SCT88: Box Held Against Vertical Surface—Frictional Force on Box	179
B3-RT89: Boxes Held Against Vertical Surfaces—Frictional Forces on the Wall	180
B3-QRT90: Moving Stacked Blocks—Friction Forces.....	181
B3-QRT91: Stacked Blocks Slowing Down—Friction Forces.....	182
B3-WWT92: Two Asteroids—Gravitational Force on Each.....	183
B3-SCT93: Three Asteroids in a Line—Calculation of Mass	184
B3-QRT94: Three Objects Exerting Gravitational Forces—Net Force.....	185
B3-WWT95: Three Asteroids in a Line—Mass of Asteroid	186
B3-QRT96: Two Objects—Gravitational Force on Each.....	187
B3-RT97: Three Asteroids in a Line—Net Force.....	188
B3-WWT98: Astronaut near a Planet and a Moon—Gravitational Force	189
B3-CT99: Astronaut near a Moon—Gravitational Force	190
B3-SCT100: Ball Whirled in Vertical Circle—Net Force on Ball	191
B3-CT101: Skateboarder on Circular Bump—Weight and Normal Force.....	192
B3-SCT102: Child on a Swing—Tension	193
B4 Work and Energy.....	194
B4-RT01: Moving Balls I—Kinetic Energy.....	194
B4-RT02: Moving Balls II—Kinetic Energy.....	195
B4-WWT03: Object Changing Velocity—Work.....	196
B4-RT04: Cars and Barriers—Stopping Force in Same Distance	197
B4-RT05: Cars and Barriers—Stopping Distance with the Same Force	198
B4-RT06: Cars Changing Velocity—Work Done.....	199
B4-RT07: Bouncing Cart—Change in Kinetic Energy	200
B4-RT08: Equal Forces on Boxes—Work Done on Box	201
B4-RT09: Velocity-Time Graph I—Work Done on Box	202
B4-RT10: Velocity-Time Graph II—Work Done on Box.....	203
B4-RT11: Force Pushing Box—Change in Kinetic Energy	204
B4-QRT12: Two Ball Systems—Kinetic Energy of System.....	205
B4-WWT13: Boat Position-Time Graphs—Work.....	206
B4-BCT14: Tugboat Changing Velocity I—Work & Kinetic Energy Bar Chart.....	207
B4-BCT15: Object Changing Velocity I—Work and Kinetic Energy Bar Chart	208
B4-BCT16: Object Changing Velocity II—Work and Kinetic Energy Bar Chart.....	209
B4-BCT17: Tugboat Changing Velocity II—Work and Kinetic Energy Bar Chart	210
B4-LMCT18: Block Pushed on Incline—Work Done.....	211
B4-SCT19: Blocks Sliding Down Frictionless Ramps—Work by the Normal Force	212
B4-SCT20: Blocks Sliding Down Frictionless Ramps—Work by the Earth.....	213
B4-QRT21: Block on Ramp with Friction—Work.....	214
B4-QRT22: Block on Ramp with Friction—Work and Energy	215
B4-CT23: Thrown Javelins—Horizontal Force.....	216
B4-SCT24: Skaters Pushing off Each Other—Force.....	217
B4-RT25: Arrows Shot from Buildings—Final Speed.....	218
B4-RT26: Toboggans Going Down Slippery Hills—Speed at Bottom	219
B4-CT27: Roller Coaster Ride over Lagoon—Maximum Height.....	220
B4-CT28: Skateboarders on a Hill—Time, Speed, Kinetic Energy, and Work.....	221
B4-BCT29: Block Pushed on Smooth Ramp—Energy Bar Chart.....	222

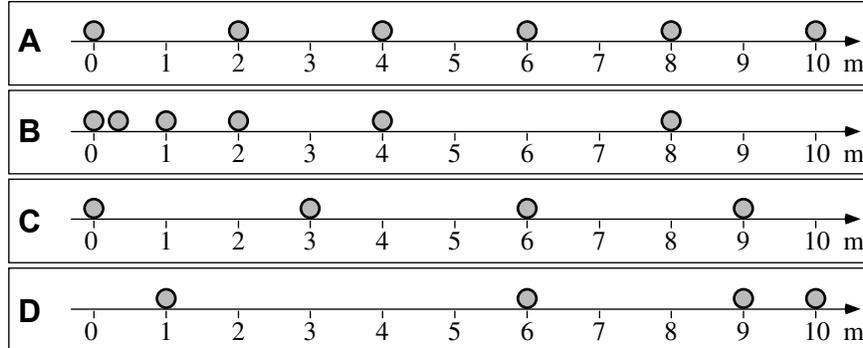
B4-BCT30: Box Pulled on Smooth Surface—Energy Bar Chart	223
B4-BCT31: Box Pulled on Rough Surface—Energy Bar Chart	224
B4-BCT32: Lifted Box Moving Upward I—Energy Bar Chart	225
B4-BCT33: Lifted Box Moving Upward II—Energy Bar Chart I	226
B4-BCT34: Lifted Box Moving Upward II—Energy Bar Chart II	227
B4-BCT35: Box Attached to Spring—Energy Bar Chart.....	228
B4-BCT36: Moving Block Pushed up a Smooth Ramp—Energy Bar Chart	229
B4-BCT37: Skateboarder Launched by a Spring I—Energy Bar Chart	230
B4-BCT38: Skateboarder Launched by a Spring II—Energy Bar Chart	231
B4-WBT39: Energy Bar Chart I—Physical Situation	232
B4-WBT40: Energy Bar Chart II—Physical Situation	233
B4-WWT41: Sliding Box—Energy Bar Chart	234
B4-WWT42: Box on Sloping Hill—Energy Bar Chart	235
B4-QRT43: Dropped Rock—Energy Bar Chart	236
B4-WBT44: Energy Bar Chart—Physical Situation.....	237
B4-RT45: Sliding Masses on Incline—Kinetic Energy	238
B4-RT46: Sliding Masses on Incline—Change in Potential Energy	239
B4-CT47: Race up a Hill I—Work and Power	240
B4-CT48: Race up a Hill II—Work and Power.....	241
B4-CT49: Car Race—Work and Power	242
B5 Momentum and Impulse	243
B5-RT01: Moving Ball I—Momentum and Kinetic Energy	243
B5-RT02: Force Pushing Box I—Change in Momentum.....	244
B5-RT03: Force Pushing Box II—Impulse	245
B5-RT04: Force Pushing Box III—Change in Momentum	246
B5-QRT05: Amanda and Bertha’s Car Race—Work and Impulse	247
B5-RT06: Moving Ball II—Momentum and Kinetic Energy.....	248
B5-QRT07: Blocks Sliding Down Frictionless Ramps—Work and Momentum	249
B5-RT08: Cars Stopped by Constant Force Barriers—Stopping Time	250
B5-QRT09: Object Changing Velocity—Direction of the Impulse.....	251
B5-RT10: Bouncing Cart I—Change in Momentum.....	252
B5-RT11: Bouncing Cart II—Change in Momentum	253
B5-QRT12: Bouncing Cart—Direction of the Change in Momentum	254
B5-RT13: Cars—Change in Momentum During a Change of Velocity	255
B5-SCT14: Object Changing Velocity I—Impulse	256
B5-WWT15: Object Changing Velocity II—Impulse	257
B5-WWT16: Object Changing Velocity III—Impulse.....	258
B5-WWT17: Object Changing Velocity IV—Impulse.....	259
B5-RT18: Force-Time Graph I—Impulse Applied to Box	260
B5-WWT19: Force-Time Graph II—Impulse Applied to Box.....	261
B5-WWT20: Two Skaters Pushing off Each Other—Force.....	262
B5-CT21: Two Boxes on a Frictionless Surface—Momentum and Speed.....	263
B5-WWT22: Ball Hitting a Wall—Momentum	264
B5-RT23: Colliding Carts Sticking Together—Final Speed	265
B5-SCT24: Two Moving Carts—Result of Collision.....	266
B5-CT25: Bullet Strikes a Wooden Block—Block and Bullet Speed After Impact.....	267
B5-SCT26: Colliding Carts That Stick Together—Final Kinetic Energy	268
B5-QRT27: Colliding Steel Balls—Momentum and Impulse Direction	269
B5-RT28: Colliding Ball Systems—Momentum Before and After Colliding.....	270
B5-QRT29: Colliding Ball Systems—Momentum Direction before and after Colliding.....	271
B6 Rotation.....	272
B6-CRT01: Pulley and Weight—Angular Velocity-Time and Acceleration-Time Graphs	272
B6-CRT02: Angular Velocity-Time Graph—Angular Acceleration-Time Graph	273
B6-RT03: Three-Dimensional Point Objects—Moment of Inertia about the x -Axis	274
B6-RT04: Flat Objects—Moment of Inertia Perpendicular to Surface	275

B6-QRT05: Pulleys with Different Radii—Rotation and Torque	276
B6-RT06: Spheres Rolling—Radius.....	277
B6-QRT07: Three Equal Forces Applied to a Rectangle—Net Torque Direction	278
B6-RT08: Spheres Rolling—Rotational Kinetic Energy.....	279
B6-QRT09: Three Forces Applied to a Rectangle—Torque Direction	280
B6-CT10: Fishing Rod—Weight of Two Pieces	281
B6-RT11: Suspended Signs—Torque.....	282
B6-RT12: Four Forces Acting on a Hexagon—Torque about Center	283
B6-QRT13: Balance Beam—Motion after Release.....	284
B6-RT14: Rolling Objects Released from Rest—Time Down Ramp	285
B6-WWT15: Pulley with Hanging Weights—Angular Acceleration.....	286
B6-RT16: Tilted Pivoted Rods with Various Loads—Force to Hold Rods.....	287
B6-CT17: Special Rod—Moment of Inertia.....	288
B6-CT18: Tilted Pivoted Rods with Various Loads—Force to Hold Rods.....	289
B6-RT19: Horizontal Pivoted Rods with Loads I—Force to Hold.....	290
B6-LMCT20: Horizontal Pivoted Board with Load II—Force to Hold Board.....	291
B6-RT21: Hanging Weights on Fixed Disks—Torque.....	292
B6-RT22: Systems of Point Masses—Difficult to Rotate	293
B6-RT23: Meter Stick with Hanging Mass I—Difficulty Holding	294
B6-CT24: Horizontal Meter Stick with Two Hanging Masses—Torque	295
B6-RT25: Four Forces Acting on a Piece of Plywood—Torque	296
B6-QRT26: Four Forces Acting on a Piece of Plywood—Rotation Direction.....	297
B6-BCT27: Hoop Rolling up a Ramp—Rotational Energy Bar Chart.....	298
B6-BCT28: Solid Disk Rolling up a Ramp—Rotational Energy Bar Chart.....	299
B6-QRT29: Solid Sphere Rolling Along a Track—Location at Highest Point	300
B6-RT30: Moving down a Ramp—Maximum Height on the Other Side of a Ramp.....	301
B6-RT31: Objects Moving down Ramps—Speed at Bottom.....	302
B6-RT32: Blocks on Rotating Disc—Horizontal Frictional Force.....	303
B7 Oscillatory Motion	304
B7-RT01: Mass on Horizontal Spring Systems I—Oscillation Frequency	304
B7-RT02: Swinging Simple Pendula—Oscillation Frequency.....	305
B7-RT03: Swinging Sphere on Long Strings—Time for One Swing	306
B7-RT04: Mass on Horizontal Spring Systems II—Period of Oscillating Mass.....	307
B7-QRT05: Position-Time Graph of a Cart Attached to a Spring—Mass and Period.....	308
B7-CRT06: Velocity-Time Graph—Frequency and Period	309
B7-SCT07: Mass on a Vertical Spring—Acceleration	310
B7-LMCT08: Mass Connected to a Horizontal Spring—Frequency.....	311
B7-QRT09: Oscillation Displacement-Time Graph—Kinematic Quantities.....	312
B7-SCT10: Horizontal Oscillating Cart—Period	313
B7-QRT11: Oscillating Mass on Spring Displacement-Time Graph—Directions.....	314
B7-SCT12: Mass Oscillating on a Vertical Spring—Energy.....	315
B7-QRT13: Displacement-Time Graph—Energy Quantities	316
B7-BCT14: Oscillating Mass on Spring Displacement-Time Graph—Energy	317

B1 MOTION IN ONE DIMENSION

B1-RT01: STROBE PHOTOGRAPHS OF SPHERES—DISPLACEMENT I

In each case, a sphere is moving from left to right next to a tape marked in meters. A strobe (flash) photograph is taken every second, and the location of the sphere is recorded. The total time intervals shown are not the same for all spheres.



Rank the magnitude of the displacement over the first 2 seconds.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

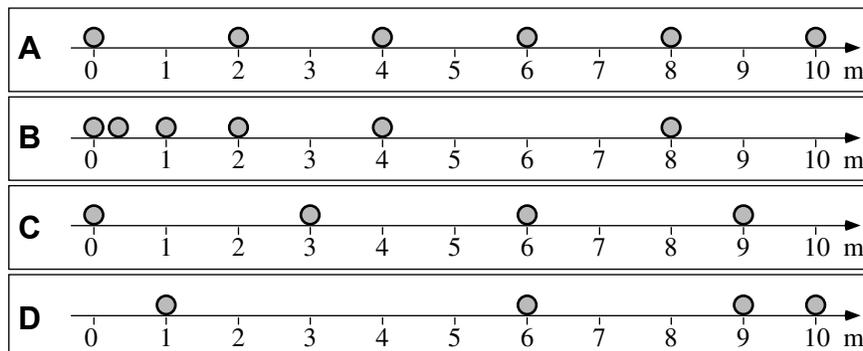
Explain your reasoning.

Answer: $D > C > A > B$.

The displacements for C during the first two seconds was 6 m reading directly from the drawing, for D it was 8 m being the difference between 9 m and 1m, the location at zero, next was A at 4 m and the least is B at 1m.

B1-RT02: STROBE PHOTOGRAPHS OF SPHERES—DISPLACEMENT II

In each case, a sphere is moving from left to right next to a tape marked in meters. A strobe (flash) photograph is taken every second, and the location of the sphere is recorded. The total time intervals shown are not the same for all spheres.



Rank the magnitude of the displacement over the first 3 seconds.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

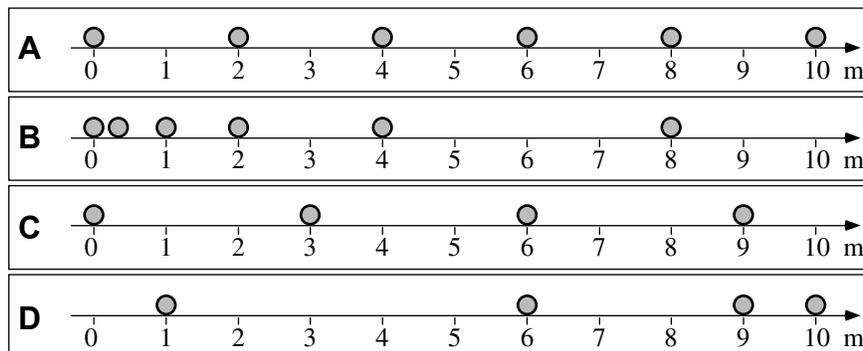
Explain your reasoning.

Answer: C = D > A > B.

The displacements for C and D during the first three seconds was 9 m, next was A at 6 m and least is B at 2 m.

B1-RT03: STROBE PHOTOGRAPHS OF SPHERES—AVERAGE VELOCITY I

In each case, a sphere is moving from left to right next to a tape marked in meters. A strobe (flash) photograph is taken every second, and the location of the sphere is recorded. The total time intervals shown are not the same for all spheres.



Rank the magnitude of the average velocity over the first 3 seconds.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

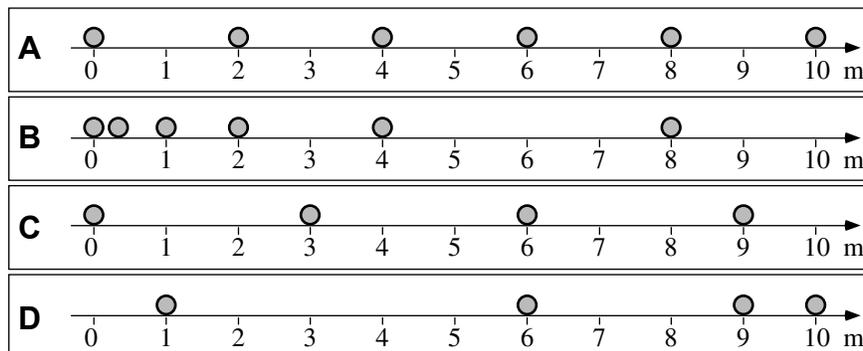
Explain your reasoning.

Answer: $C = D > A > B$.

Average velocity is defined as the displacement during a time interval divided by the time interval. The time interval is the same for all four cases, so the average velocities are determined by the displacements, which are proportional to the distances traveled in the first three seconds.

B1-RT04: STROBE PHOTOGRAPHS OF SPHERES—AVERAGE VELOCITY II

In each case, a sphere is moving from left to right next to a tape marked in meters. A strobe (flash) photograph is taken every second, and the location of the sphere is recorded. The total time intervals shown are not the same for all spheres.



Rank the magnitude of the average velocity over the first 2 seconds.

<input style="width: 90%;" type="text"/>	OR	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

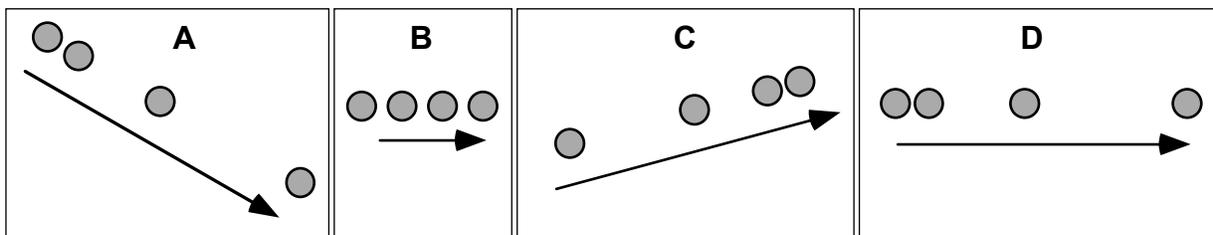
Explain your reasoning.

Answer: $D > C > A > B$.

Average velocity is defined as the displacement during a time interval divided by the time interval. The time interval is the same for all four cases, so the average velocities are determined by the displacements, which are proportional to the distances traveled in the first two seconds. The displacements for C during the first two seconds was 6 m reading directly from the drawing, for D it was 8 m being the difference between 9 m and 1m, the location at zero, A is 4 m and smallest is B at 1m.

B1-RT05: BALL STROBE DIAGRAMS—AVERAGE VELOCITY

The following drawings represent strobe (flash) photographs of a ball moving in the direction of the arrow. The circles represent the positions of the ball at succeeding instants of time. The time interval between successive positions is the same in all cases.



Rank the magnitude of the ball's average velocity in the last time interval.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

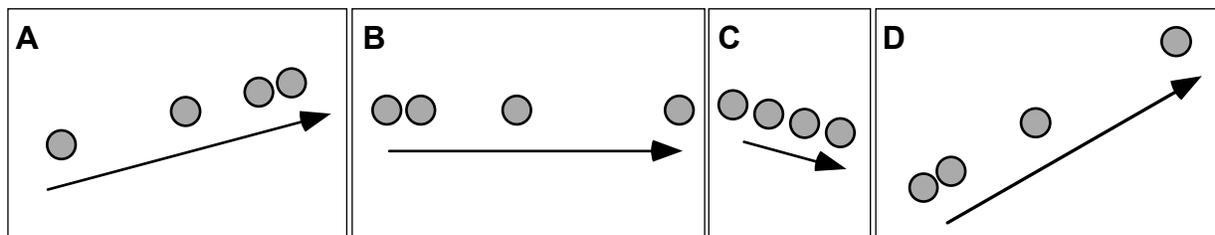
Explain your reasoning.

Answer: $A = D > B > C$.

Since the time intervals are the same in all cases, the distance between any two adjacent positions of the ball will be proportional to the magnitude of the average velocity of the ball in the time interval between when those photographs were taken. By comparing the spacing between the last two positions for each case we can determine the magnitude of the average velocity in the last time interval.

B1-RT06: BALL STROBE DIAGRAMS—ACCELERATION

The following drawings represent strobe (flash) photographs of a ball moving in the direction of the arrow. The circles represent the positions of the ball at succeeding instants of time. The time interval between successive positions is the same in all cases. Assume all accelerations are constant.



Rank the magnitude of the acceleration based on the drawings.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

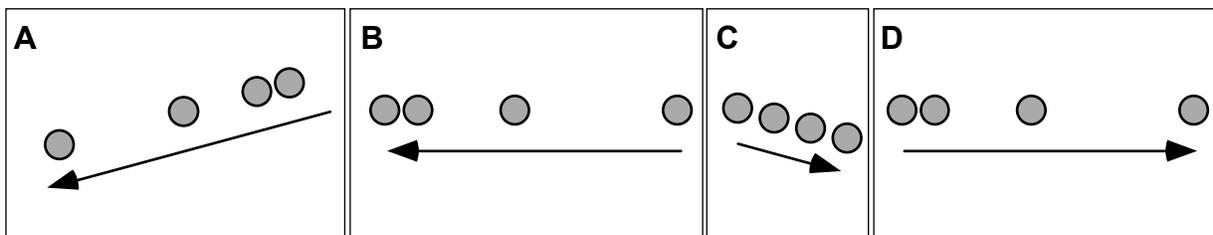
Answer: $B = D > A > C$.

The spacing of the successive position changes given determine the direction of the acceleration and give an indication of the relative magnitude of the acceleration. In cases B and D, the acceleration is the same, in the direction of the arrow, and fairly large, because the speed of the ball is increasing quite a bit in each time interval.

In case A the acceleration points opposite to the direction of the arrow and has a slightly smaller magnitude than B and D. In case C, the acceleration is zero since the ball has a constant direction and rate of motion.

B1-RT07: BALL STROBE DIAGRAMS—ACCELERATION

The following drawings represent strobe (flash) photographs of a ball moving in the direction of the arrow. The circles represent the positions of the ball at succeeding instants of time. The time interval between successive positions is the same in all cases. Assume all accelerations are constant.



Rank the magnitude of the acceleration based on the drawings.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

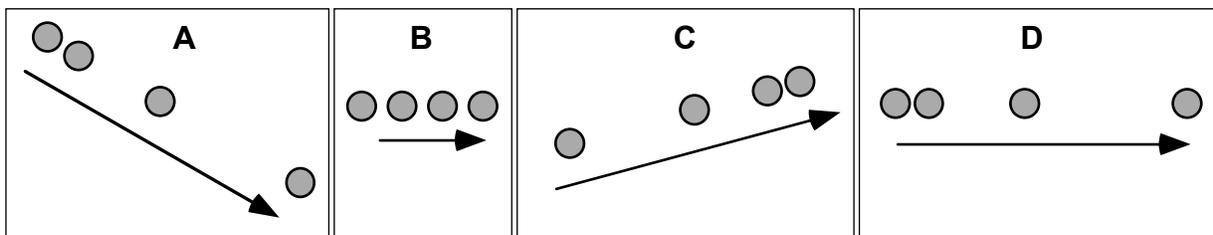
Explain your reasoning.

Answer: $B = D > A > C$.

The acceleration is the rate of change of the velocity. Since the velocity of C is constant the acceleration is zero for that case. For the others we can look at the changes in the average velocities, which are proportional to the changes in the spacing between successive locations. These are equivalent for B and D, but A has a smaller magnitude acceleration.

B1-RT08: BALL STROBE DIAGRAMS—SPEED

The following drawings represent strobe (flash) photographs of a ball moving in the direction of the arrow. The circles represent the positions of the ball at succeeding instants of time. The time interval between successive positions is the same in all cases.



Rank the ball's average speed in the last time interval.

1	2	3	4	OR	All	All	Cannot
Greatest			Least		the same	zero	determine

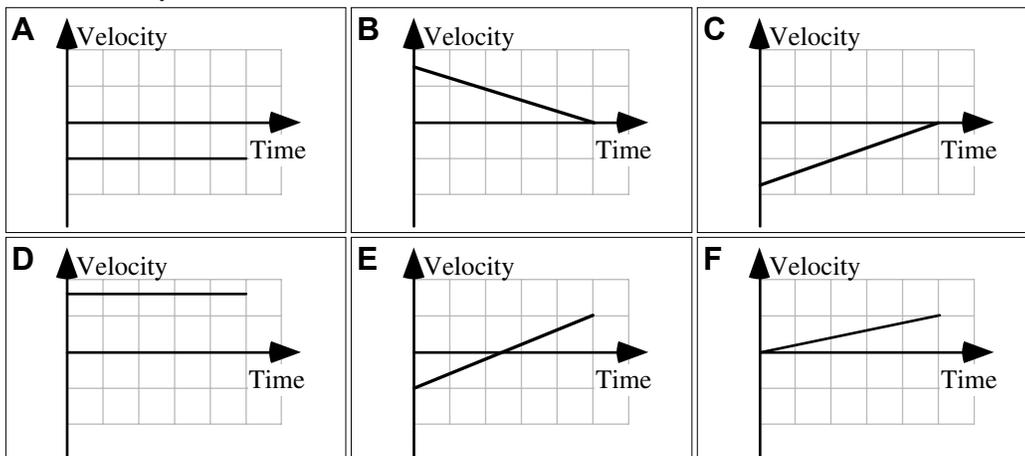
Explain your reasoning.

Answer: $A = D > B > C$.

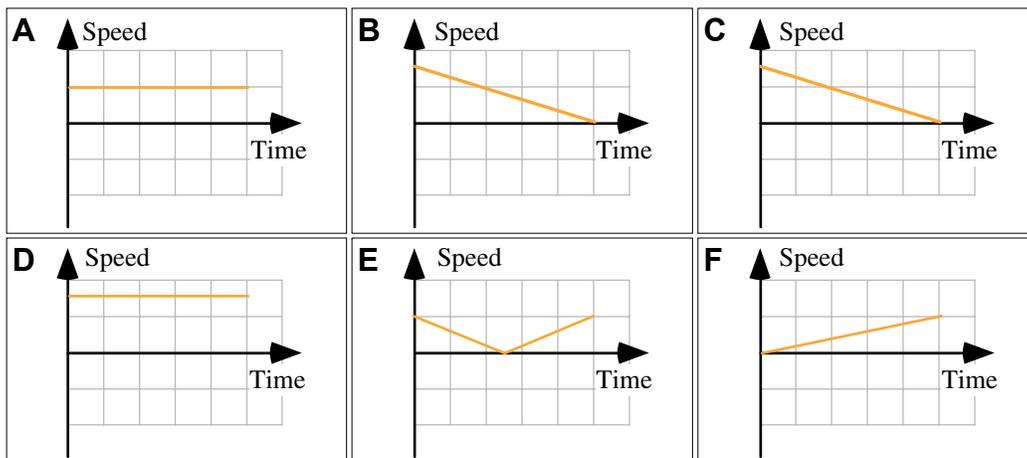
Since the time intervals are the same in all cases, the distance between any two adjacent positions of the ball will be proportional to the average speed of the ball in the time interval between when those photographs were taken. By comparing the spacing between the last two positions for each case we can determine the average speed in the last time interval.

B1-CRT09: VELOCITY-TIME GRAPHS—SPEED-TIME GRAPHS

Velocity versus time graphs for six toy cars that are traveling straight along a hallway are shown. All graphs have the same time and velocity scales.



Draw below the speed versus time graphs for these graphs.

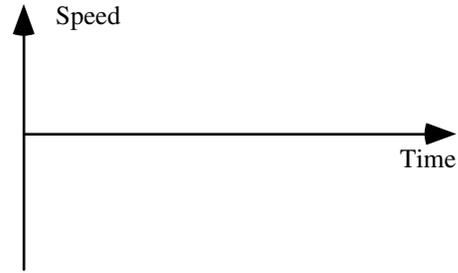
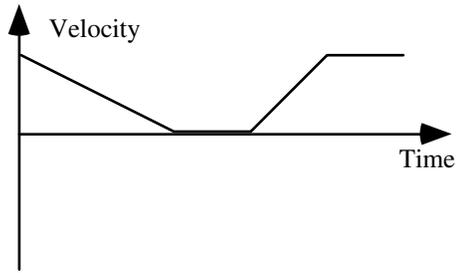


Explain your reasoning.

Answer: Graph A shows a constant velocity motion which means the speed is also constant and positive since speed is a scalar. Graph B shows a decreasing positive velocity which means the speed is decreasing. Graph C is also a decreasing velocity, but a decreasing negative velocity, which means the speed, again positive because it is a scalar, is decreasing. Graph D is another constant velocity, so we again have a constant speed. Graph E shows a situation where the velocity is initially negative, but there is a constant positive acceleration so the negative velocity decreases constantly to zero and then the velocity increases, but in the positive direction. That means the speed decreases to zero, and then increases constantly. Graph F is an increasing positive velocity, which means the speed is increasing constantly.

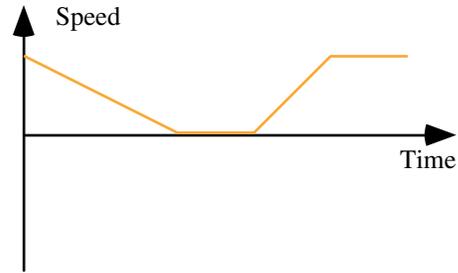
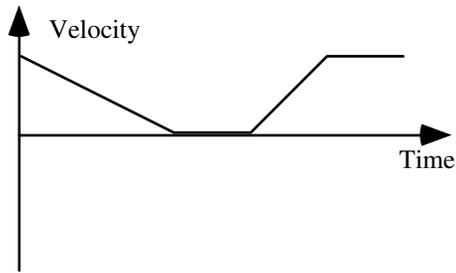
B1-CRT10: VELOCITY-TIME GRAPH—SPEED-TIME GRAPHS

Given this velocity-time graph, draw the corresponding speed-time graph.



Explain your reasoning.

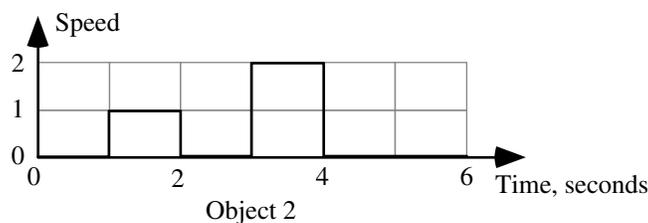
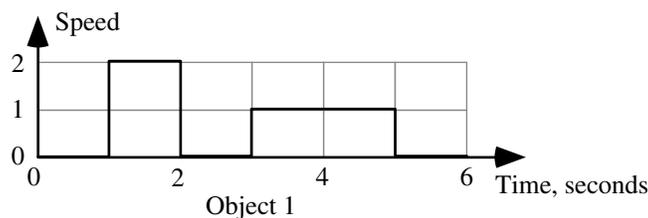
Answer:



The instantaneous speed is the magnitude of the instantaneous velocity so in this case where the velocity is always positive the speed versus time graph will follow the velocity versus time graph.

B1-WWT11: SPEED-TIME GRAPHS OF TWO OBJECTS—DISPLACEMENT

The graphs below show the speed of two objects during the same time interval.



A student considering these two graphs states:

“Object 1 will be farther from its starting point after this 6-second interval than Object 2 because Object 1 had a larger displacement than Object 2.”

What, if anything, is wrong with the student’s statement? If something is wrong, explain the error and how to correct it. If the graph is correct, explain why.

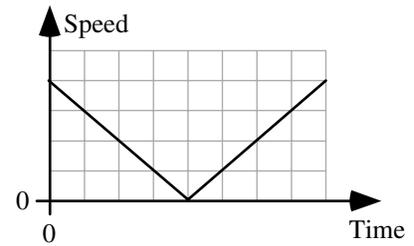
Answer: The student’s statement is problematic since we cannot determine the displacements from these graphs. The area under the line or curve in a speed versus time graph tells us the distance traveled, but we have no idea whether the objects were traveling in one direction or if they reversed direction. Consequently, we cannot say anything about displacements.

B1-WWT12: BALL THROWN UPWARD AND COMES BACK DOWN—SPEED-TIME GRAPH

A ball is thrown straight upward and falls back to the same height. A student makes this graph of the speed of the ball as a function of time.

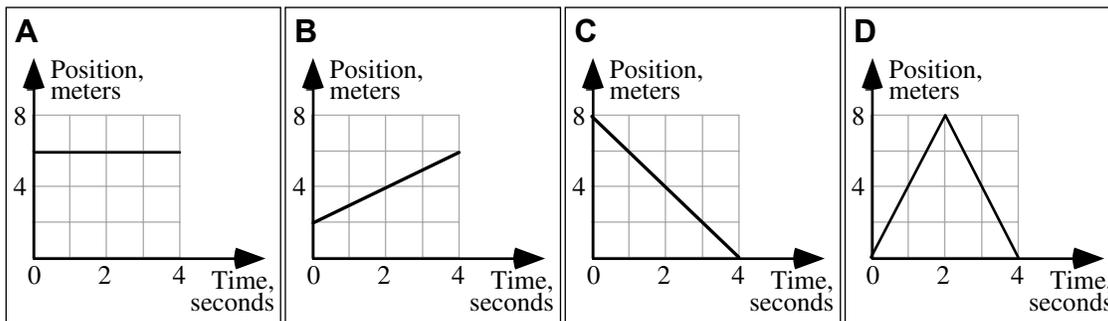
What, if anything, is wrong with the student's graph? If something is wrong, explain the error and how to correct it. If the graph is correct, explain why.

Answer: The graph is correct for the speed of the object because the ball will slow down, stop at an instant, and then speed up as it falls.



B1-RT13: POSITION-TIME GRAPHS—DISPLACEMENT

Each graph below shows the position of an object as a function of time.



Rank the magnitude of the displacement during the time interval from 0 to 4 seconds.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

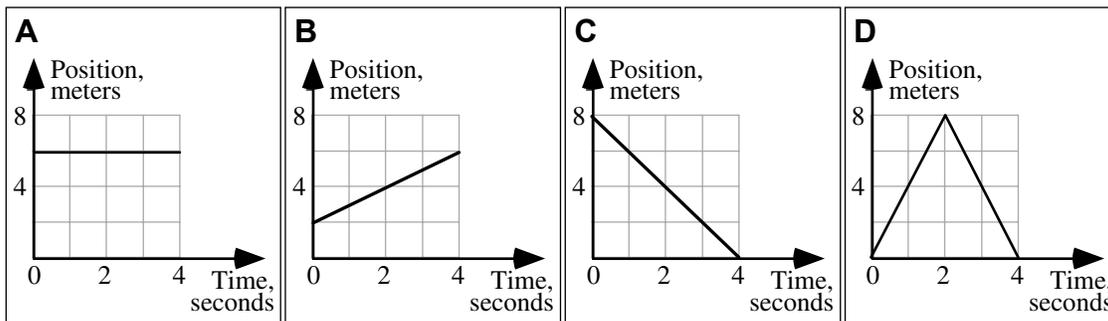
Explain your reasoning.

Answer: $C > B > A = D$.

The displacement is given by the change in position over the time interval. Object C has a displacement with a magnitude of 8 m; B's displacement has a magnitude of 4 m and A and D both have zero displacements since they are at the same point at the start and end of the time interval.

B1-RT14: POSITION-TIME GRAPHS—AVERAGE SPEED

Each graph below shows the position of an object as a function of time.



Rank the average speed of the object during the time interval from 0 to 4 seconds.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

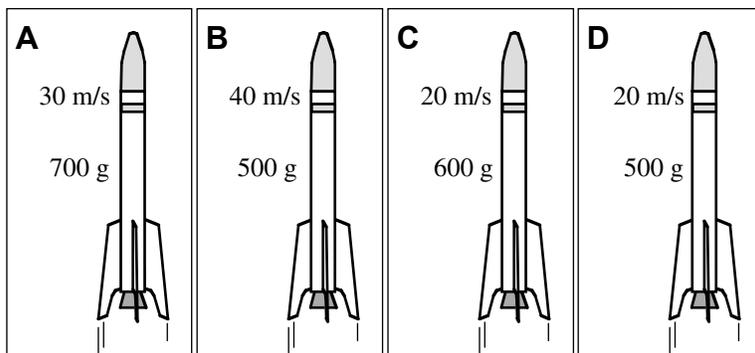
Explain your reasoning.

Answer: $D > C > B > A$.

The average speed is the distance traveled divided by the time interval. For D, the average speed is 4 m/s (the object traveled 8 meters in one direction and then 8 meters back for a total of 16 meters in 4 seconds); for C it is 2 m/s; for B it is 1 m/s; and for A it is zero.

B1-RT15: VERTICAL MODEL ROCKETS—MAXIMUM HEIGHT

The model rockets depicted below have just had their engines turned off when they are at the same height. All of the rockets are aimed straight up, but their speeds differ. Although they are the same size and shape, the rockets carry different loads, so their masses differ. The specific mass and speed for each rocket is given in each figure.



Rank the maximum height the model rockets will reach.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

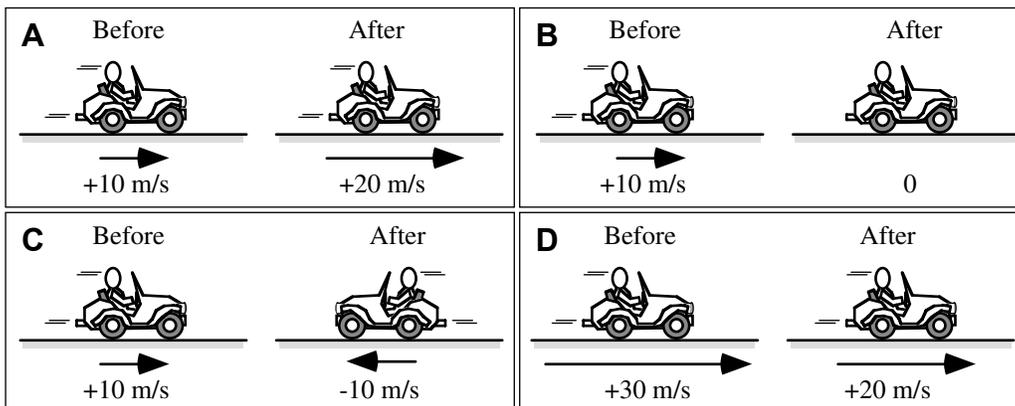
Explain your reasoning.

Answer: $B > A > C = D$.

All four experience the same acceleration of 9.8 m/s^2 downward, so their maximum heights are determined by their speed. Ignoring air resistance all objects have the same acceleration in the Earth's gravitational field whatever their masses.

B1-RT16: CARS—CHANGE OF VELOCITY

In each figure below, a car's velocity is shown before and after a short time interval.



Rank the magnitude of the change in velocity during the time interval.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

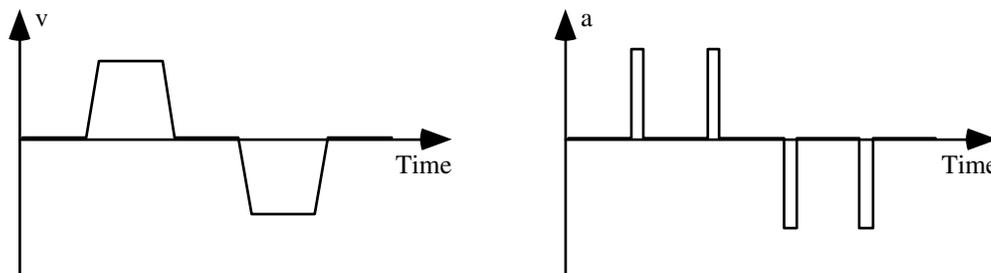
Explain your reasoning.

Answer: C > A = B = D.

The magnitude of the change in velocity for C is 20 m/s while the other three all experience a change of 10 m/s in the magnitude of their velocity.

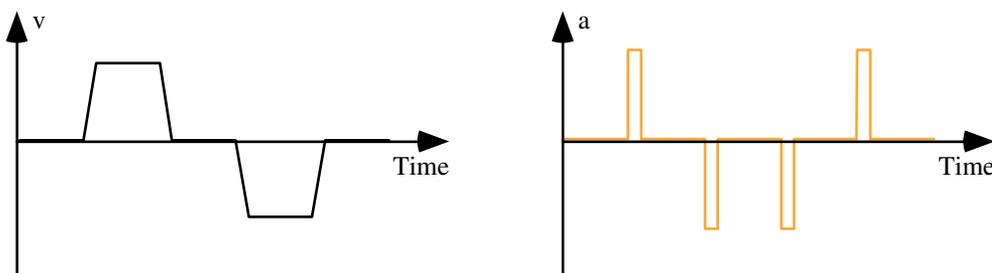
B1-WWT17: VELOCITY-TIME GRAPH—ACCELERATION-TIME GRAPH

A student obtains a graph of an object's velocity versus time and then draws the graph of the acceleration versus time for the same time interval.



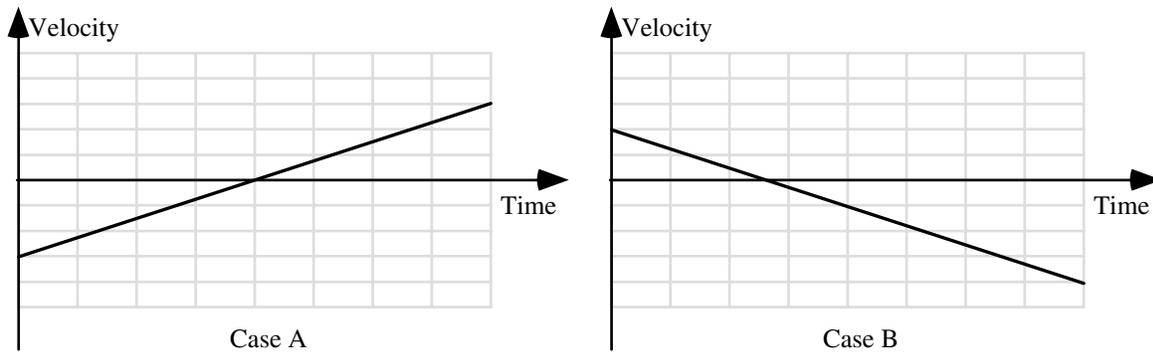
What, if anything, is wrong with the graph of the acceleration versus time? If something is wrong, identify it and explain how to correct it. If the graph is correct, explain why.

Answer: The acceleration is the slope of the velocity graph. Thus, the second and fourth peaks should be reversed as shown below because the sign of the acceleration is the same as the sign of the slope of the velocity-time graph.



B1-CT18: VELOCITY-TIME GRAPHS—DISPLACEMENT

The graphs represent the velocity of two toy robots moving in one dimension for a particular time interval. Both graphs have the same time and velocity scales.



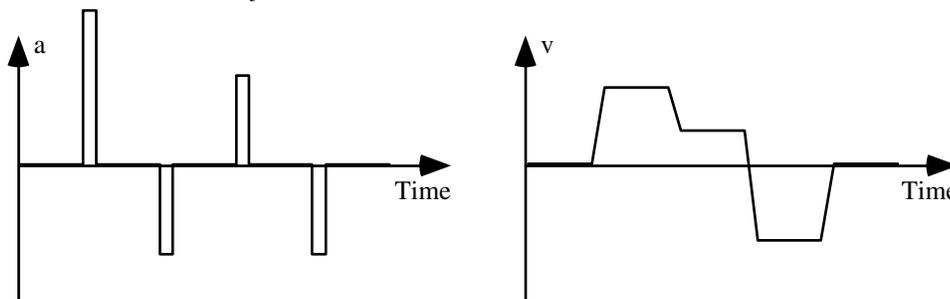
Is the magnitude of the displacement of the robot for the entire time interval shown (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: The displacement is the area between the velocity-time line, or curve, and the time axis. The displacement in Case A is zero (there is a negative displacement for the first half and an equal magnitude positive displacement for the second half) while the displacement for case B is negative. The magnitude of the displacement is greater in case B.

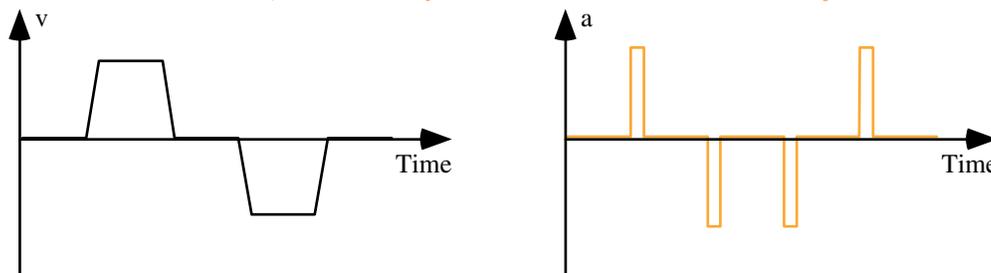
B1-WWT19: ACCELERATION-TIME GRAPH—VELOCITY-TIME GRAPH

A student obtains a graph of an object's acceleration versus time and then draws the graph of the velocity versus time for the same time interval. The object starts from rest.



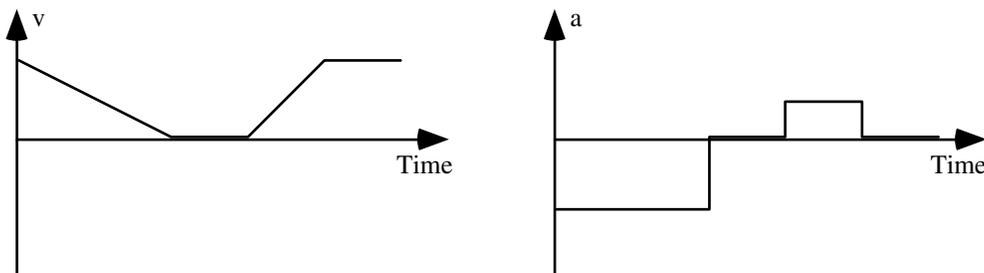
What, if anything, is wrong with the graph of velocity versus time? If something is wrong, identify it and explain how to correct it. If the graph is correct, explain why.

Answer—the change in velocity is related to the area under the acceleration vs time graph. Thus the velocity graph should be like the graph below. The second, third and fourth accelerations are all the same magnitude and are smaller than the initial acceleration, so the velocity does not return to zero at the end of the interval.



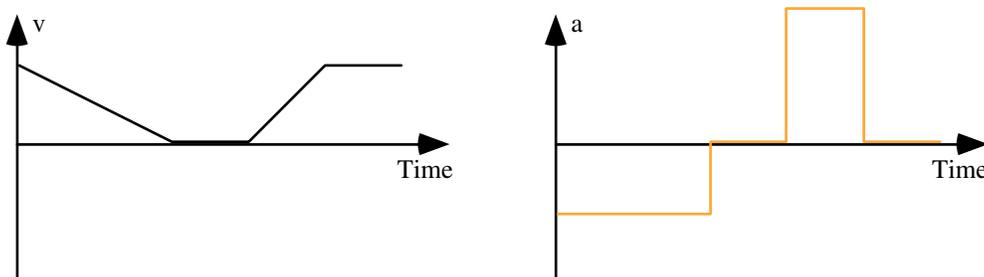
B1-WWT20: VELOCITY-TIME GRAPH—ACCELERATION-TIME GRAPH

A student obtains a graph of an object's velocity versus time and then draws the graph of the acceleration versus time for the same time interval.



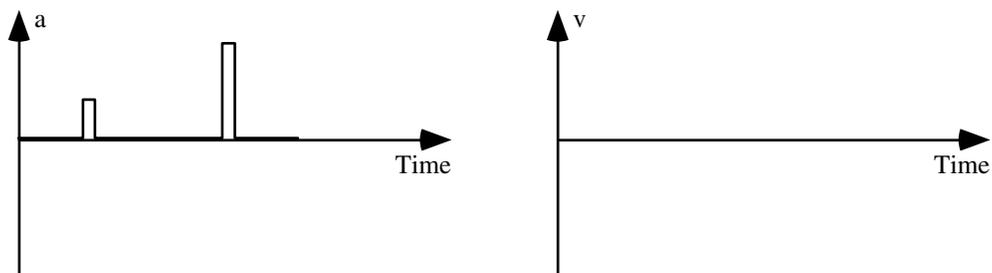
What, if anything, is wrong with the graph of the acceleration versus time? If something is wrong, identify it and explain how to correct it. If the graph is correct, explain why.

Answer: Since the acceleration-time graph is related to the slope of the velocity-time graph, the magnitude of the acceleration should be proportional to the slope of the velocity-time graph at each point. For the third segment of the velocity-time graph, the (positive) slope has a greater magnitude than the (negative) slope of the first segment, and so the acceleration should have a greater positive value for this segment than the negative value of the first segment. (The change in velocity for the object over the entire time interval is zero, so the area under the curve of the acceleration time graph should be zero. We need to adjust the acceleration graph to bring the velocity back to the original value, and the rectangles above and below the zero axis should have the same area.)



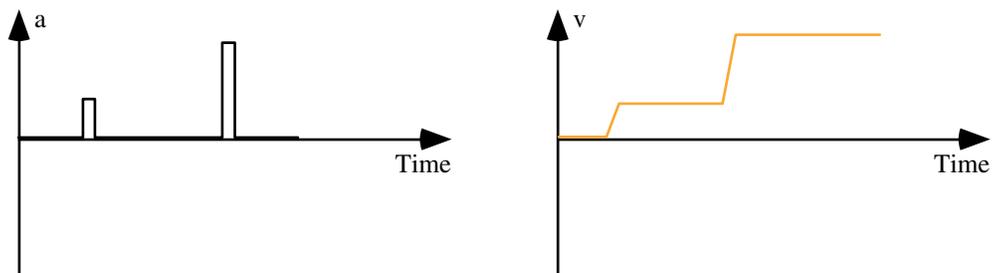
B1-CRT21: ACCELERATION-TIME GRAPH—VELOCITY-TIME GRAPH

Sketch a possible velocity versus time graph given the acceleration graph for the same time interval.



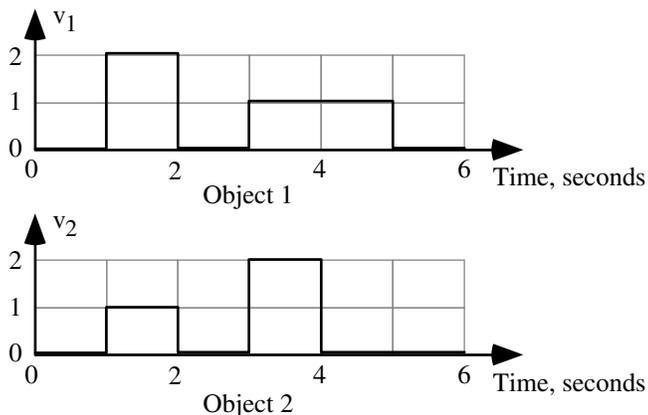
Explain your reasoning.

Answer: The change in the velocity is related to the area under the acceleration graph. The second blip is taller than the first so it contains more area. Consequently it represents a greater change in velocity. Since there is no particular initial velocity given, any graph of the same shape but starting at some other initial velocity would also be a correct choice.



B1-CT22: VELOCITY-TIME GRAPHS OF OBJECTS—DISPLACEMENT

The graphs below show the velocity of two objects during the same time interval.



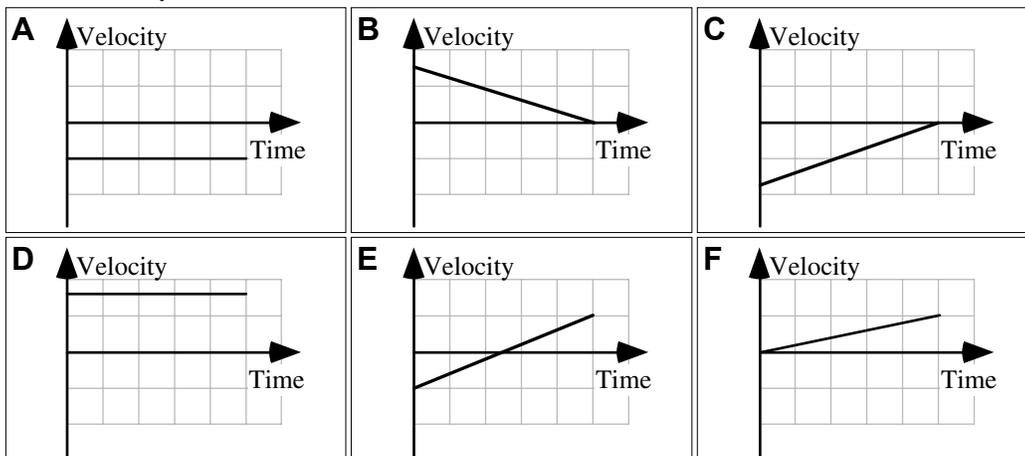
For the 6-second time interval shown, is the displacement of Object 1 in the upper graph (i) *greater than*, (ii) *equal to*, or (iii) *less than* the displacement of Object 2 in the lower graph? _____

Explain your reasoning.

Answer: The displacement is greater for Object 1 since the displacement is equal to the area under the line or curve representing the motion in a graph of velocity vs. time.

B1-RT23: VELOCITY-TIME GRAPHS—DISPLACEMENT

Shown below are six velocity-time graphs for toy robots that are traveling along a straight hallway. All graphs have the same time and velocity scales.



Rank the magnitudes of the displacements during these intervals.

						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest							Least		

Explain your reasoning.

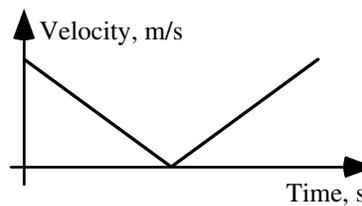
Answer: $D > A > B = C > F > E$

Since these are velocity versus time graphs the displacements are given by the areas “under” (between the lines and the time axis) the lines in the graphs.

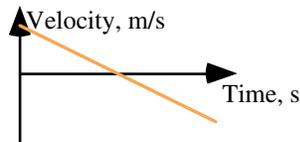
B1-WWT24: BALL THROWN UPWARD AND COMES BACK DOWN—VELOCITY-TIME GRAPH

A ball is thrown straight upward and falls back to the same height. A student makes this graph of the velocity of the ball as a function of time.

What, if anything, is wrong with the student's graph? If something is wrong, explain the error and how to correct it. If the graph is correct, explain why.

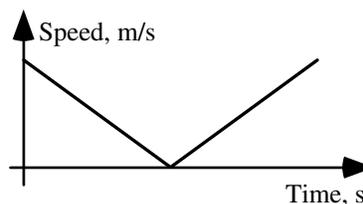


Answer: The line should go across the axis and continue in a straight line into the negative region since the velocity is negative on the way back down. The slope should be constant since the acceleration is constant. Note the graph would be correct if it were a graph of the speed of the object.



B1-SCT25: BALL THROWN UPWARD—GRAPH OF SPEED-TIME

A ball is thrown straight upward and falls back to the same height. A student makes the graph of the speed of the ball as a function of time. Three students who are discussing this graph make the following contentions:



Akira: “I don’t think this can be correct because the sign of the acceleration changes on this graph, but the acceleration on the ball will be constant.”

Burt: “No, I think this is right because it is only showing what happens to the speed, which will decrease to zero at the top and then increase as the ball falls. Since the slopes for both segments are the same except for sign that means the acceleration is constant.”

Catalina: “This graph makes sense to me because it shows the speed decreasing on the way up. But I disagree with Burt, because I think this means the acceleration is also decreasing until the ball gets to the top and stops. Then both the speed and acceleration increase as the ball falls down again.”

With which, if any, of these three students do you agree?

Akira _____ Burt _____ Catalina _____ None of them _____

Explain your reasoning.

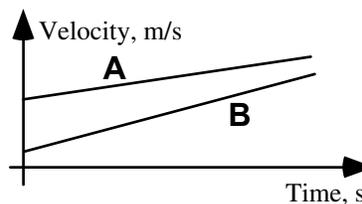
Answer: Burt is correct because a speed versus time graph will have a negative slope as the ball moves upward, since it is slowing down, and then a positive slope coming down since it is speeding up. But both lines have to have the same slope value since the acceleration is constant throughout.

B1-WWT26: VELOCITY-TIME GRAPH OF TWO OBJECTS—FASTEST OBJECT

A student is shown the velocity-time graphs for two objects and is asked to decide which object is moving faster. The student responds:

“B is faster because it has the steeper slope.”

What, if anything, is wrong with the student’s statement? If something is wrong, explain the error and how to correct it. If the statement is correct, explain why.

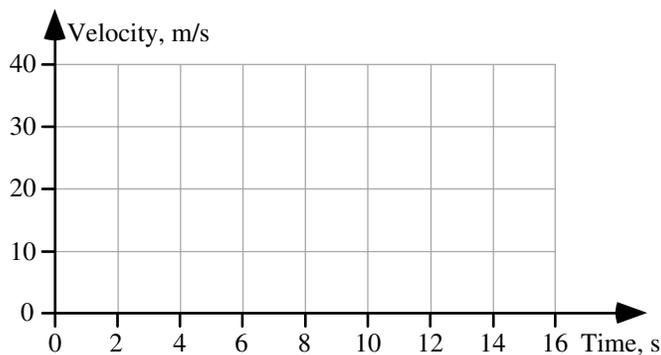


Answer: A is faster because its velocity value is above that of B at any time shown on the graph, which means at any time shown it is moving faster than B is. The slope of the velocity-time graph is the acceleration. Therefore, B has the larger acceleration during the entire time because it has the larger slope.

B1-CRT27: TRAVELING STUDENTS—VELOCITY-TIME GRAPH

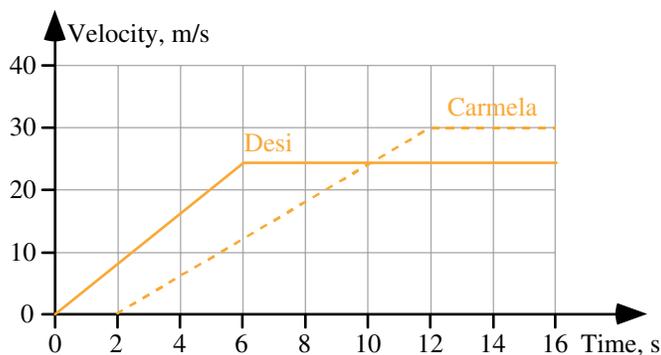
Carmela and Desi leave a parking lot separately and drive west. They both start from rest. Desi leaves first, traveling with an acceleration of 4 m/s^2 west for the first 6 seconds, and then driving at a constant velocity. Two seconds after Desi started, Carmela starts with an acceleration of 3 m/s^2 west for 10 seconds, and then she drives at a constant velocity.

Graph the velocity of both travelers as a function of time up to $t = 16$ seconds starting at time $t = 0$ when Desi leaves the classroom. Use a solid line for Desi's velocity and a dashed line for Carmela's velocity.



Explain your reasoning.

Answer: Since Desi left first we can take his starting time as zero. His velocity increases as a constant rate of 4 m/s each second until his speed is 24 m/s . We will take West as the positive region of the vertical axis on the graph. Carmela's starting time is 2 s and her speed increases at 3 m/s each second until she reaches a speed of 30 m/s . She will also be moving West.

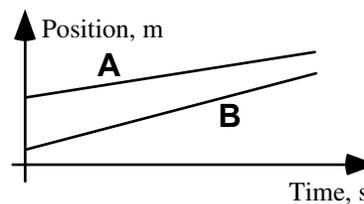


B1-WWT28: POSITION-TIME GRAPH OF TWO OBJECTS—FASTEST OBJECT

A student is shown the position-time graphs for two objects and is asked to decide which object is moving faster. The student responds:

“B is faster because it has the steeper slope.”

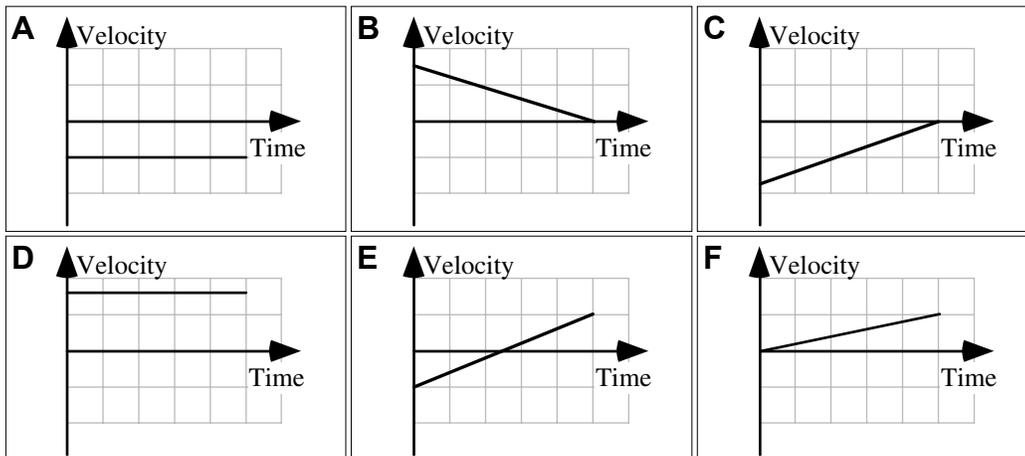
What, if anything, is wrong with the student’s statement? If something is wrong, explain the error and how to correct it. If the statement is correct, explain why.



Answer: There is nothing wrong. To find the speed from a position-time graph we need to take the slope of the line because that tells us how rapidly the position changes with time.

B1-RT29: VELOCITY-TIME GRAPHS—DISTANCE TRAVELED

Velocity-time graphs for six toy robots that are traveling along a straight hallway are shown. All graphs have the same time and velocity scales.



Rank the distance traveled during these intervals.

						OR	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	2	3	4	5	6		All	All	Cannot
Greatest					Least		the same	zero	determine

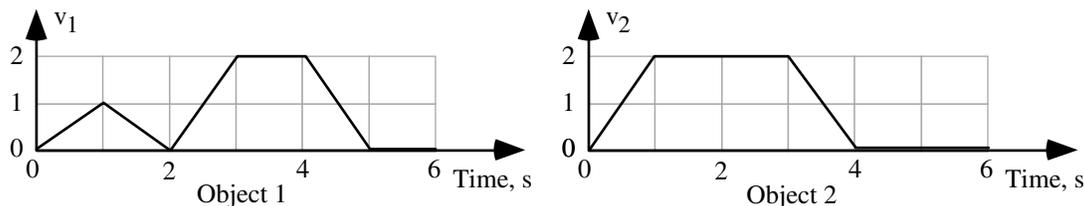
Explain your reasoning.

Answer: $D > A > B = C > E = F$.

The distance traveled is the sum of the absolute values of the areas between the horizontal axis and the line on each graph. For graphs of motion that don't change direction (all cases except E), the magnitude of the displacement is the same as the distance traveled. For case, E, the distance traveled is the sum of the distance traveled backward and the distance traveled forward. The absolute value of the two areas in case E is the same as the area in case F.

B1-SCT30: VELOCITY-TIME GRAPHS OF OBJECTS—DISPLACEMENT

The graphs below show the velocity of two objects during the same time interval.



Three students are discussing the displacements of these objects for this interval.

Amos: “I think Object 2 will have the greater displacement because it gets to a higher speed faster than Object 1.”

Badu: “No, Object 1 will have the greater displacement because it travels for a longer time than Object 2.”

Candi: “I agree with Amos, but for a different reason. Object 2 has the larger displacement because the area under the graph is greater.”

With which, if any, of these three students do you agree?

Amos _____ Badu _____ Candi _____ None of them _____

Explain your reasoning.

Answer: Candi is correct, because the displacement is determined by the area under a velocity-time graph, which is larger for object 2.

B1-QRT31: POSITION OR VELOCITY GRAPHS—CHANGE DIRECTION

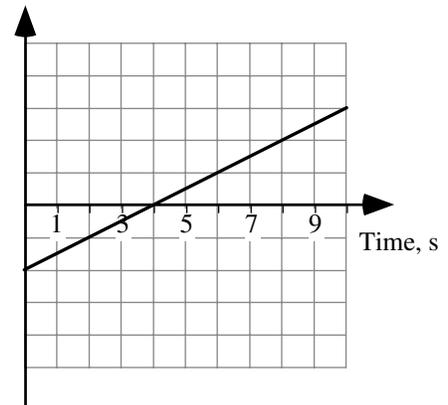
The graph shown is for an object in one-dimensional motion.

(a) If the vertical axis of the graph is position, does the object ever change direction?

If so, at what time or times does this change in direction occur?

Explain your reasoning.

Answer: No, for this case the velocity of the object is always positive since it is the slope of this line. Since the velocity doesn't change direction, the object doesn't change direction.



(b) If the vertical axis of the graph is velocity, does the object ever change direction?

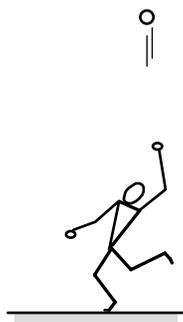
If so, at what time or times does this change in direction occur?

Explain your reasoning.

Answer: For this case the velocity of the object is zero at 4 seconds and negative before that point and positive after that point so it changes direction once at 4 seconds.

B1-WWT32: BALL THROWN STRAIGHT UPWARD—TIME TO REACH TOP

A student throws a ball straight upward. A friend times how long it takes the ball to reach its maximum height.



The student predicts:

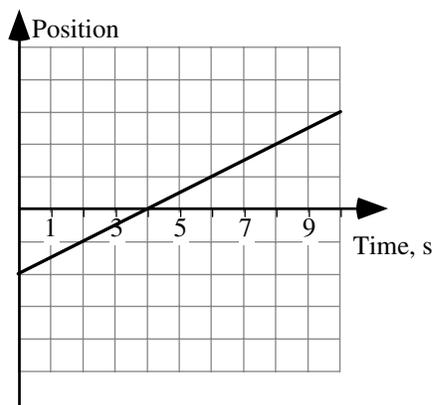
“Faster things take less time. If I throw the ball faster, it will reach its highest point in less time.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The statement is incorrect. The ball that is thrown faster will also go higher. Faster things take less time to travel the same distance, but in this case the two balls don't travel the same distance. Both balls will have the same acceleration, 10 m/s^2 downward, so both balls slow down at the same rate, by 10 m/s for every second they are in the air. Since the faster ball starts with a greater initial speed, it will take more time to reach a speed of zero, when it is at its maximum height.

B1-QRT33: POSITION-TIME GRAPH—DIRECTION

A bicyclist is moving along a straight street oriented east—west. In drawing the graph, positions to the east of the origin were marked as positive and positions to the west were marked as negative.



(a) At 1 second, is the cyclist moving?

If so, in what direction?

Explain your reasoning.

Answer: At one second the cyclist is moving East since the slope of the graph is positive at that instant.

(b) At 1 second, is the cyclist accelerating?

If so, in what direction?

Explain your reasoning.

Answer: The line has a constant slope throughout, so the acceleration is zero throughout.

(c) At 9 seconds, is the cyclist moving?

If so, in what direction?

Explain your reasoning.

Answer: At nine seconds the cyclist is still moving East since the slope of the line is still positive.

(d) At 9 seconds, is the cyclist accelerating?

If so, in what direction?

Explain your reasoning.

Answer: No, the cyclist moves with a constant velocity throughout.

(e) At 4 seconds, is the cyclist moving?

If so, in what direction?

Explain your reasoning.

Answer: At four seconds the cyclist is moving East since the slope is positive.

(f) At 4 seconds, is the cyclist accelerating?

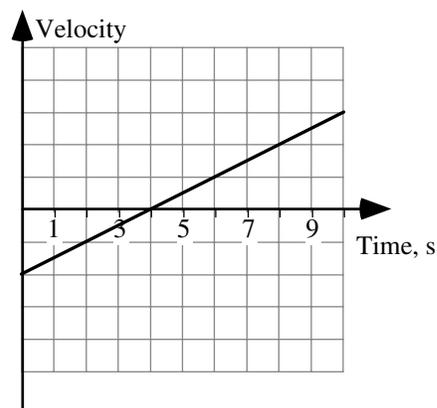
If so, in what direction?

Explain your reasoning.

Answer: No, the cyclist moves with a constant velocity throughout.

B1-QRT34: VELOCITY-TIME GRAPH—DIRECTION

A unicyclist, someone riding a single-wheel cycle, is moving along a straight street oriented east—west. In drawing the graph, east was taken as the positive direction and west the negative direction.



(a) At 1 second, is the cyclist moving?

If so, in what direction?

Explain your reasoning.

Answer: The cyclist is moving West at one second since the velocity is negative at that time.

(b) At 1 second, is the cyclist accelerating?

If so, in what direction?

Explain your reasoning.

Answer: The cyclist is accelerating to the East since the slope of the line, which tells us the acceleration, is positive. The acceleration is constant throughout the interval graphed.

(c) At 9 seconds, is the cyclist moving?

If so, in what direction?

Explain your reasoning.

Answer: At nine seconds the cyclist is moving East since the velocity is positive at that time.

d) At 9 seconds, is the cyclist accelerating?

If so, in what direction?

Explain your reasoning.

Answer: The cyclist is accelerating to the East throughout.

(e) At 4 seconds, is the cyclist moving?

If so, in what direction?

Explain your reasoning.

Answer: At four seconds the cyclist is stopped instantaneously while changing direction.

(f) At 4 seconds, is the cyclist accelerating?

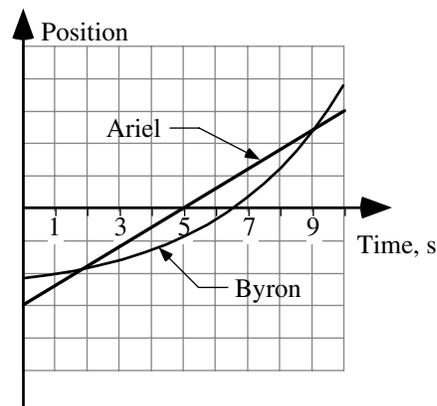
If so, in what direction?

Explain your reasoning.

Answer: As stated above the cyclist is accelerating to the East throughout.

B1-QRT35: POSITION-TIME GRAPHS OF CHILDREN—KINEMATIC QUANTITIES

The position-time graph shown represents the motion of two children, Ariel and Byron, who are moving along a narrow, straight hallway.



(a) Do either of the children ever change direction?

If so, at what time or times does this change in direction occur?

Explain your reasoning.

Answer: The velocity of the object is given by the slope of the graph, and the slope of the graph is positive for both children at all times shown. So both children are moving in the same direction along the hallway at all times and do not change direction.

(b) Are the two children ever at the same position along the hallway?

If so, at what time or times does this happen?

Explain your reasoning.

Answer: The two children will be in the same position along the hallway for times that the graphs of their motions have the same position value. The lines cross at 2 seconds and at 9 seconds, so they are at the same position at these times.

(c) Do the two children ever have the same speed?

If so, at what time or times does this happen?

Explain your reasoning.

Answer: The velocity of the object is given by the slope of the graph, and the speed is the absolute value of the velocity. The two children have the same speed when the slopes of the graphs have the same absolute value. A tangent line drawn to a point on the curve representing Byron's position gives his speed, and at around 6 seconds this tangent will be parallel to the line representing Ariel's position. The two children have the same speed at about 6 seconds.

(d) Do the two children ever have the same acceleration?

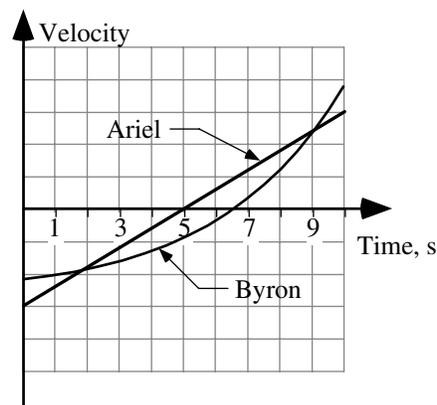
If so, at what time or times does this happen?

Explain your reasoning.

Answer: The velocity of the object is given by the slope of the graph, and for Ariel this slope is constant in time. So Ariel's velocity does not change with time, and Ariel's acceleration is zero. That is, Ariel is moving down the hallway at a constant speed. On the other hand, the slope of Byron's position-time graph is always changing, meaning that Byron's velocity is always changing with time. So Byron has a nonzero acceleration at all times. The two children never have the same acceleration.

B1-QRT36: VELOCITY-TIME GRAPHS OF CHILDREN—KINEMATIC QUANTITIES

The velocity-time graph shown represents the motion of two children, Ariel and Byron, who are moving along a narrow, straight hallway.



(a) Do either of the children ever change direction?

If so, at what time or times does this change in direction occur?

Explain your reasoning.

Answer: The velocity of each child is given by the value on the vertical axis of the graph, so Ariel's velocity changes from negative to positive at time 5 seconds, and Byron's velocity changes from negative to positive approximately at time 6.5 seconds. So Ariel changes direction at 5 seconds and Byron changes direction at 6.5 seconds. Between 5 and 6.5 seconds, the children are moving in opposite directions along the hallway.

(b) Do the two children ever have the same velocity?

If so, at what time or times does this occur?

Explain your reasoning.

Answer: The velocity of each child is given by the value of the y-axis of the graph, so Ariel's velocity is the same as Byron's velocity at times 2 seconds and 9 seconds.

(c) Do the two children ever have the same acceleration?

If so, at what time or times does happen?

Explain your reasoning.

Answer: The acceleration of each child is given by the slope of the graph, so Ariel's acceleration is the same as Byron's acceleration when the graphs have the same slope, at around time 6 seconds.

B1-WBT37: POSITION EQUATION—PHYSICAL SITUATION

Describe the motion of an object that is represented by the following equation:

$$x = 33.6 \text{ m} - (2.8 \text{ m/s})t$$

Answer: This object began 33.6 m away from the origin and traveled at a constant velocity of 2.8 m/s in the negative direction towards the origin, reaching the origin at 12 seconds. If it continues to move at 2.8 m/s in the negative direction, then it will be moving away from the origin at this speed at all times after 12 seconds.

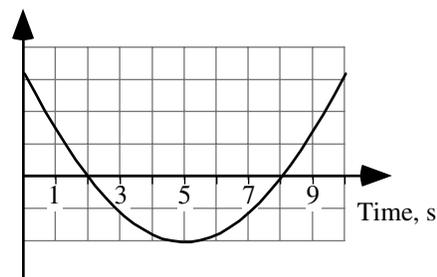
B1-QRT38: POSITION OR VELOCITY GRAPHS—CHANGE DIRECTION

The graph shown is for an object in one-dimensional motion. The vertical axis is not determined, so it is not labeled.

(a) If the vertical axis is position, does the object ever change direction?

If so, at what time or times does this change in direction occur?

Explain your reasoning.



Answer: For this case the velocity of the object is given by the slope of the graph, and the object has a negative velocity from time zero to 5 seconds. After 5 seconds, the object has a positive velocity. So the object changed direction at 5 seconds.

(b) If the vertical axis is velocity, does the object ever change direction?

If so, at what time or times does this change in direction occur?

Explain your reasoning.

Answer: In this case the magnitude of the velocity of the object is given by the value on the vertical axis of the graph, and the object has a positive velocity from time zero to 2 seconds. From 2 seconds to 8 seconds, the object has a negative velocity. After 8 seconds, the object has a positive velocity. So the object changed direction at 2 seconds, and again at 8 seconds.

B1-SCT39: BICYCLIST ON A STRAIGHT ROAD—AVERAGE SPEED

Three students are discussing the motion of a bicyclist who travels at a steady 18 m/s for 10 minutes, then at 6 m/s for 20 minutes, and finally at 12 m/s for 15 minutes along a straight, level road. Students make the following contentions about the bicyclist’s average speed for the overall trip:

Aaron: “The average speed is 12 m/s because you add the three velocities, but then you have to divide by three.”

Bessie: “I think you have to take the amount of time at each speed into account. The total time for the trip is 45 minutes, so the cyclist is going at 12 m/s for one-third of the time, at 6 m/s for 20/45ths of the time, and at 18 m/s for 10/45ths of the time. You’d have to weight the speeds according to the times.”

Cesar: “The average speed is 10.7 m/s because that is what you get when you divide 28,800 m, the total distance traveled on the straight road, by 2700 seconds, the total time it took.”

With which, if any, of these three students do you agree?

Aaron _____ Bessie _____ Cesar _____ None of them _____

Explain your reasoning.

Answer: Cesar is correct because the average speed is the distance traveled divided by the total time. Bessie’s technique also works, and if you carry out her proposal you get the same answer as Cesar gets: $(6 \text{ m/s})(20/45) + (12 \text{ m/s})(15/45) + (18 \text{ m/s})(10/45) = 10.7 \text{ m/s}$.

B1-QRT40: POSITION EQUATIONS—MOTION CHARACTERISTICS

Equations for the position of four objects executing one-dimension motion in the x -direction as a function of time are given.

A $x = 5 m + (3 m/s)t + (4 m/s^2)t^2$	B $x = -5 m + (3 m/s)t + (4 m/s^2)t^2$
C $x = -5 m + (3 m/s)t$	D $x = 5 m - (3 m/s)t + (8 m/s^2)t^2$

(a) What is the initial position for Object A?

Explain your reasoning.

Answer: +5 m. We get this by plugging zero in for t.

(b) What is the initial position for Object B?

Explain your reasoning.

Answer: -5 m. We get this by plugging zero in for t.

(c) What is the initial velocity for Object C?

Explain your reasoning.

Answer: +3 m/s. The coefficient of the t term is the initial velocity.

(d) What is the initial velocity for Object D?

Explain your reasoning.

Answer: -3 m/s. The coefficient of the t term is the initial velocity.

(e) What is the acceleration for Object A?

Explain your reasoning.

Answer: $8 m/s^2$. The coefficient of the t^2 term is one half the acceleration.

(f) What is the acceleration for Object D?

Explain your reasoning.

Answer: $16 m/s^2$. The coefficient of the t^2 term is one half the acceleration.

(g) What is the position for Object A at 1 second?

Explain your reasoning.

Answer: +12 m. To get this we plug 1 s in for t and solve.

(h) What is the position for Object D at 1 second?

Explain your reasoning.

Answer: 10 m. To get this we plug 1 s in for t and solve.

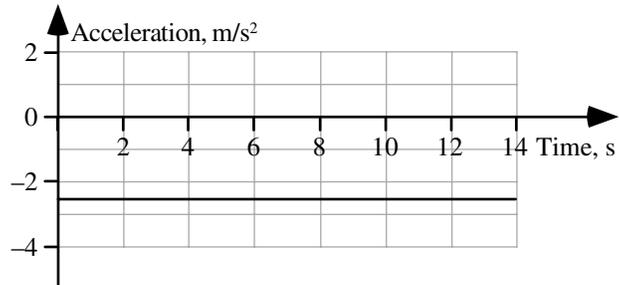
(i) Which, if any, of these objects is moving at a constant velocity and what is its velocity?

Explain your reasoning.

Answer: Object C is moving at a constant 3 m/s since there is no acceleration term in this object's equation.

B1-WWT41: ACCELERATION-TIME GRAPH—INTERPRETATION

A student is given the following acceleration versus time graph for a motorcyclist traveling along a straight, level stretch of road.



The student states:

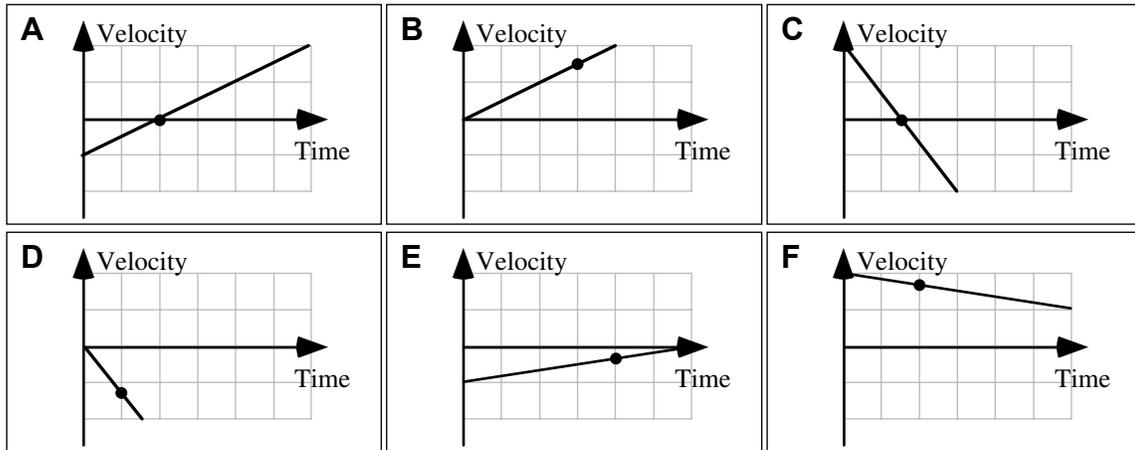
“This motorcyclist was slowing down during the period up to 14 seconds because her acceleration was negative during this period.”

What, if anything, is wrong with this student’s contention? If something is wrong, identify it and explain how to correct it. If it is correct, explain why.

Answer: This contention is problematic because the student doesn’t know whether the motorcyclist’s initial velocity was positive or negative. If the cyclist started out with an initial negative velocity then her speed was increasing, not decreasing, during the interval shown.

B1-RT42: VELOCITY-TIME GRAPHS—INSTANTANEOUS VELOCITY

The graphs below show the velocity versus time for boats traveling along a straight, narrow channel. The scales on both axes are the same for all of these graphs. In each graph, a point is marked with a dot.



Rank the magnitude of the velocity of the boat at the point indicated.

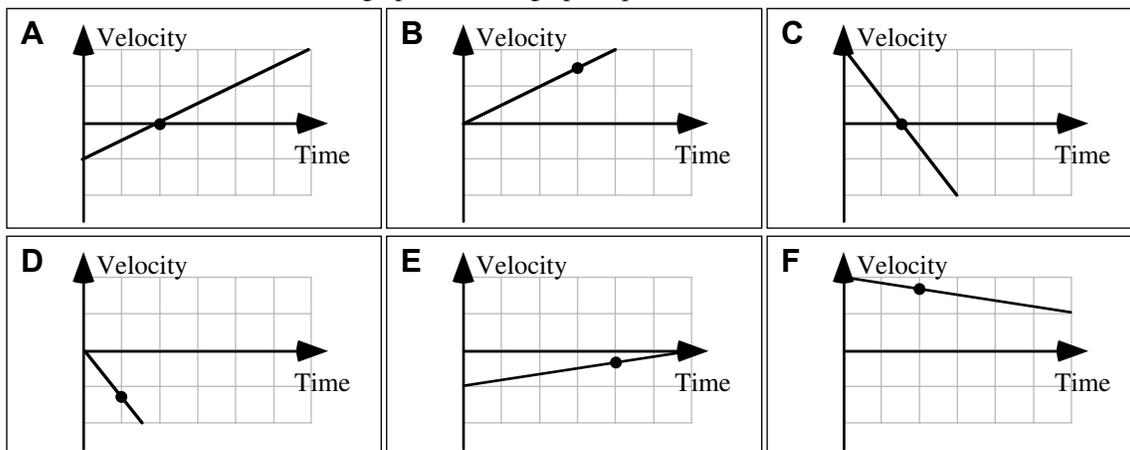
						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest									Least

Explain your reasoning.

Answer: $F > B > D > E > C = A$. These values can be read directly off the vertical axes.

B1-RT43: VELOCITY-TIME GRAPHS—ACCELERATION

The graphs below show the velocity versus time for boats traveling along a straight, narrow channel. The scales on both axes are the same for all of these graphs. In each graph, a point is marked with a dot.



Rank the magnitude of the acceleration of the boat at the point indicated.

1	2	3	4	5	6	OR	<input type="checkbox"/> All the same	<input type="checkbox"/> All zero	<input type="checkbox"/> Cannot determine
Greatest					Least				

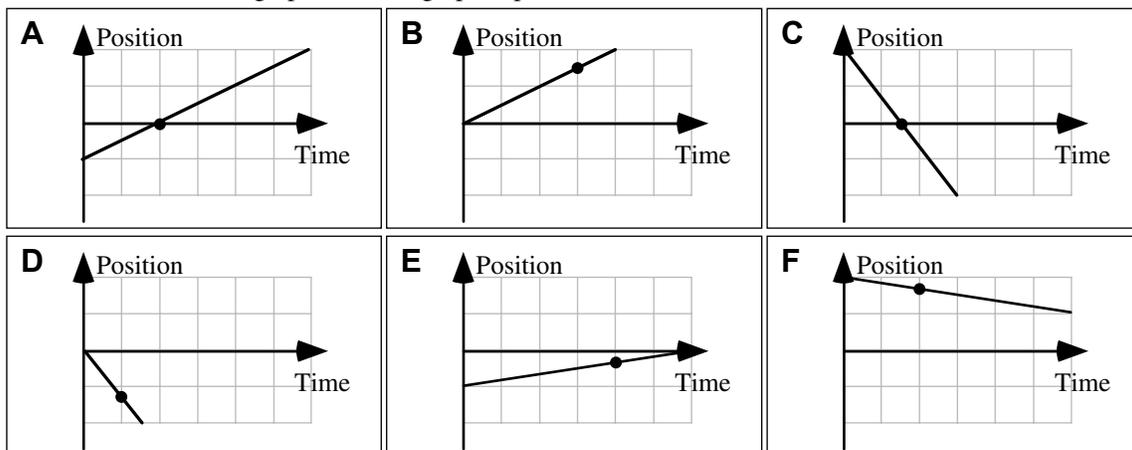
Explain your reasoning.

Answer: C = D > A = B > E = F.

The instantaneous accelerations are determined by the slopes of the velocity-time graphs at the given points on the graphs. Since these graphs are straight lines, the slopes (and the accelerations) do not change as a function of time.

B1-RT44: POSITION-TIME GRAPHS—INSTANTANEOUS SPEED

These graphs show position versus time for boats traveling along a straight, narrow channel. The scales on both axes are the same for all of these graphs. In each graph, a point is marked with a dot.



Rank the speed of the boat at the point indicated.

1	2	3	4	5	6	OR	<input type="checkbox"/> All the same	<input type="checkbox"/> All zero	<input type="checkbox"/> Cannot determine
Greatest					Least				

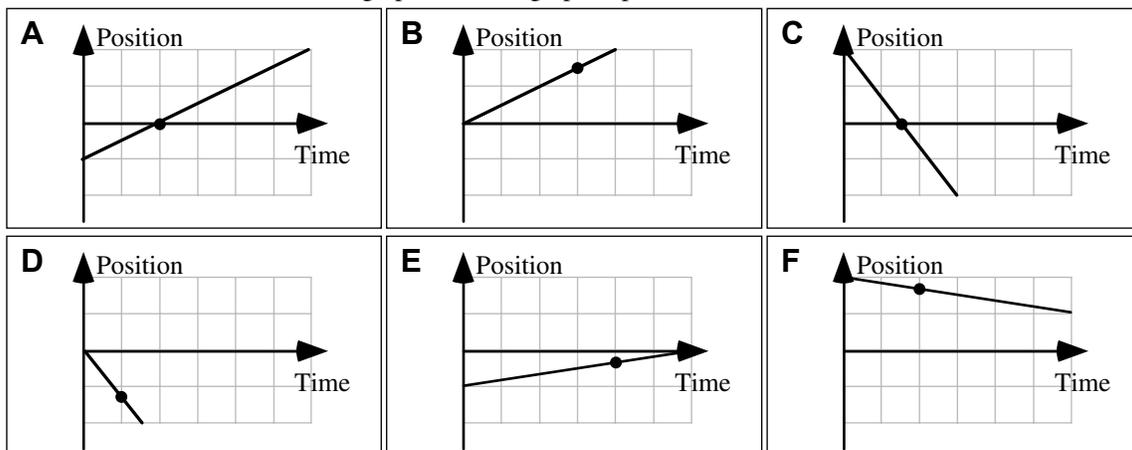
Explain your reasoning.

Answer: C = D > A = B > E = F.

The instantaneous speeds are determined by the magnitudes of the slopes of the position-time graphs. Since these graphs are straight lines, the slopes (and the speeds) do not change as a function of time.

B1-RT45: POSITION-TIME GRAPHS—INSTANTANEOUS VELOCITY

The graphs below show position versus time for six boats traveling along a straight, narrow channel. The scales on both axes are the same for all of these graphs. In each graph, a point is marked with a dot.



Rank the magnitude of the velocity of the boat at the point indicated.

1	2	3	4	5	6	OR	<input type="checkbox"/> All the same	<input type="checkbox"/> All zero	<input type="checkbox"/> Cannot determine
Greatest					Least				

Explain your reasoning.

Answer: C = D > A = B > E = F.

The magnitudes of the instantaneous velocities are determined by the magnitudes of the slopes of the position-time graphs. Since these graphs are straight lines, the slopes (and the speeds) do not change as a function of time.

B1-WWT46: BALL THROWN STRAIGHT UPWARD—TIME TO REACH TOP

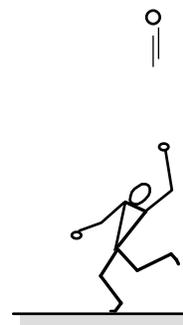
A student throws a ball straight upward. A friend times how long it takes the ball to reach its maximum height.

The student predicts:

“It takes more time to go larger distances. If I throw the ball so that it goes higher, it will take more time to get there.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

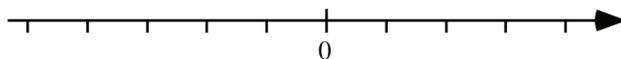
Answer: The student is correct that the ball will take longer to reach its maximum height, but care must be taken when reasoning as this student has. It is true that it takes more time to travel larger distances when the objects being compared are traveling at the same constant speed, which is not the case here. The ball that goes higher does so because it has a greater initial speed. Both balls will have the same acceleration, 10 m/s^2 downward.



B1-QRT47: POSITION, VELOCITY, AND ACCELERATION SIGNS—POSITION, DIRECTION, AND RATE

Eight possible combinations for the signs for the instantaneous position, velocity, and acceleration of an object moving in one dimension are given in the table. Above the table is a coordinate axis that shows the origin, marked 0, and that indicates that the positive direction is to the right. The three columns on the right-hand side of the table are to describe the location of the object (either left or right of the origin), the direction of the velocity of the object (either toward or away from the origin), and what is happening to the speed of the object (either speeding up or slowing down at the given instant). The appropriate descriptions for the first case are shown.

Complete the rest of the table for position, direction, and rate.



	Position	Velocity	Acceleration	Position (Left or Right)	Direction (Toward or Away from)	Rate (Speeding up or Slowing down)
A	+	+	+	Left	Away from	Speeding up
B	+	+	-			
C	+	-	+			
D	+	-	-			
E	-	+	+			
F	-	+	-			
G	-	-	+			
H	-	-	-			

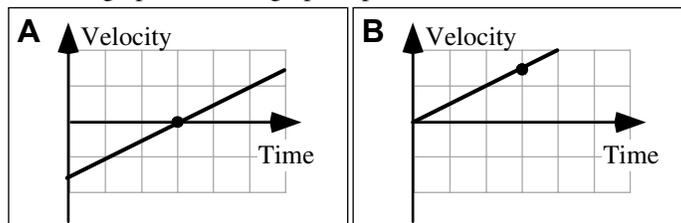
Explain your reasoning.

Answer: A positive position indicates that the object is to the right of the origin, and a negative position indicates that the object is to the left of the origin. When the position and the velocity have the same sign, the object is moving away from the origin, and when they have opposite sign the object is moving toward the origin. When the object's acceleration is the same sign as its velocity, it is speeding up, and when the signs are opposite, it is slowing down.

	Position	Velocity	Acceleration	Position (Left or Right)	Direction (Toward or Away from)	Rate (Speeding up or Slowing down)
A	+	+	+	Left	Away from	Speeding up
B	+	+	-	Left	Away from	Slowing down
C	+	-	+	Left	Toward	Slowing down
D	+	-	-	Left	Toward	Speeding up
E	-	+	+	Right	Toward	Speeding up
F	-	+	-	Right	Toward	Slowing down
G	-	-	+	Right	Away from	Slowing down
H	-	-	-	Right	Away from	Speeding up

B1-WWT48: VELOCITY-TIME GRAPHS—ACCELERATION

The graphs show the velocity versus time for two boats traveling along a straight, narrow channel. The scales on both axes are the same for the two graphs. In each graph, a point is marked with a dot.



A student who is asked to compare the accelerations at the marked points on the two graphs states:

“I think that the boat in graph B has the larger acceleration because the boat in graph A is at rest at the marked point and its acceleration is zero.”

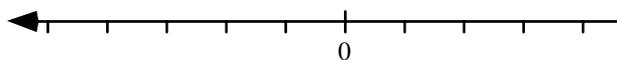
What, if anything, is wrong with this student’s contention? If something is wrong, identify it and explain how to correct it. If it is correct, explain why.

Answer: The student’s contention is wrong. Since both graphs have the same slope, both boats experience the same acceleration for the intervals shown. The boat is changing direction at the point indicated in the graph in case A, and even though it has a zero velocity at that instant, it has a nonzero acceleration.

B1-QRT49: POSITION, VELOCITY, AND ACCELERATION SIGNS—POSITION, DIRECTION, AND RATE

Eight possible signs of combinations for the instantaneous position, velocity, and acceleration of an object moving in one dimension are given in the table. Above the table is a coordinate axis that shows the origin, marked 0, and that indicates that the positive direction is to the left. The three columns on the right-hand side of the table are to describe the location of the object (either left or right of the origin), the direction of the motion of the object (either toward or away from the origin), and what is happening to the speed of the object (either speeding up or slowing down at the given instant). The appropriate descriptions for the first case are shown.

Complete the table for the object’s location and direction of motion relative to the origin and how its speed is changing.



	Position	Velocity	Acceleration	Position (Left or Right)	Direction (Toward or Away from)	Rate (Speeding up or Slowing down)
A	+	+	+	Left	Away from	Speeding up
B	+	+	-			
C	+	-	+			
D	+	-	-			
E	-	+	+			
F	-	+	-			
G	-	-	+			
H	-	-	-			

Explain your reasoning.

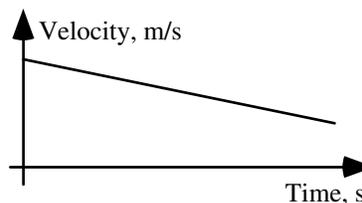
Answer: A positive position indicates that the object is to the left of the origin, and a negative position indicates that the object is to the right of the origin. When the position and the velocity have the same sign, the object is moving away from the origin, and when they have opposite signs the object is moving toward the origin. When the object’s acceleration is the same sign as its velocity, it is speeding up, and when the signs are opposite, it is slowing down.

	Position	Velocity	Acceleration	Position (Left or Right)	Direction (Toward or Away from)	Rate (Speeding up or Slowing down)
A	+	+	+	Left	Away from	Speeding up
B	+	+	-	Left	Away from	Slowing down
C	+	-	+	Left	Toward	Slowing down
D	+	-	-	Left	Toward	Speeding up
E	-	+	+	Right	Toward	Speeding up
F	-	+	-	Right	Toward	Slowing down
G	-	-	+	Right	Away from	Slowing down
H	-	-	-	Right	Away from	Speeding up

B1-WWT50: BICYCLIST ON A HILL—VELOCITY-TIME GRAPH

A bicyclist moving at high speed on a straight road comes to a hill that slopes upward gradually. She decides to coast up the hill. A physics student observing the bicyclist plots the velocity-time graph for her trip up the hill as shown.

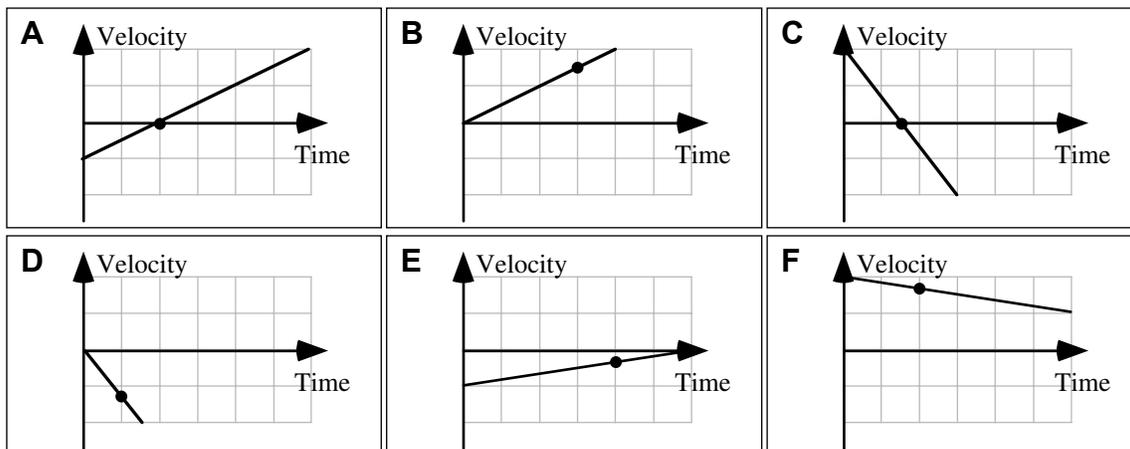
What, if anything, is wrong with this student's graph? If something is wrong, explain the error and how to correct it. If the graph is correct, explain why.



Answer: This is a correct graph. The bicyclist starts out with a large velocity that decreases continuously as she goes up the hill, so the graph is a line with a negative slope.

B1-QRT51: VELOCITY-TIME GRAPHS—DIRECTION

The graphs below show the velocity versus time for boats traveling along a straight, narrow channel. The scales on both axes are the same for all of these graphs, and the boats all start at the same origin. In each graph, a point is marked with a dot.



Indicate in the chart below if the position, velocity, and acceleration directions of the boat at the points indicated are in the positive (+), negative (-), or no direction (0)

	Position	Velocity	Acceleration
A			
B			
C			
D			
E			
F			

Explain your reasoning.

Acceleration: The accelerations are determined by the slopes of the velocity-time graphs at the points on the graphs. Since these graphs are straight lines, the slopes (accelerations) do not change as a function of time.

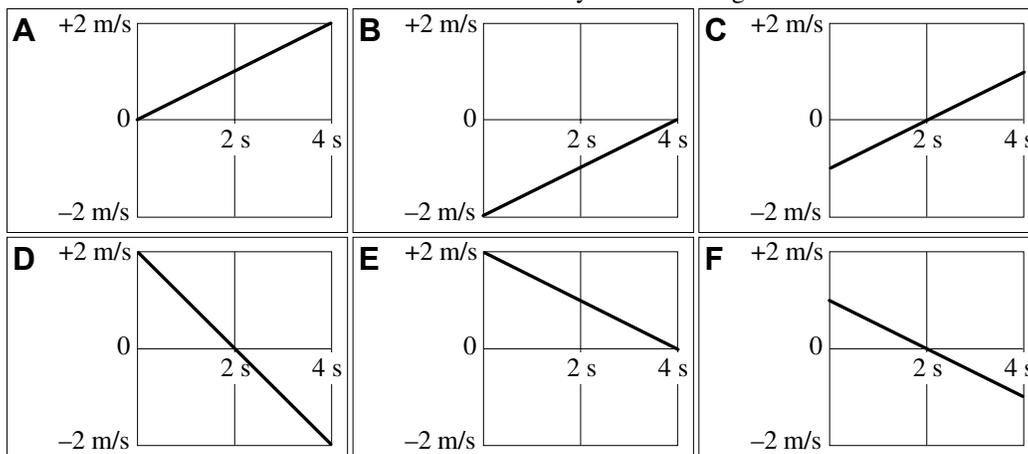
Velocity: These values can be read directly off the vertical axes.

Position: The position is the area under the graph up to the point since the boats all start from the same origin. For A, D, and E it is negative. For A it is about -1 square while for D it is about -0.5 and for E about -2.5 squares. For B the area is about +2.25squares, for C about +1.5 squares, and for F (the largest) it is about +3.5 squares.

	Position	Velocity	Acceleration
A	-	0	+
B	+	+	+
C	+	0	-
D	-	-	-
E	-	-	+
F	+	+	-

B1-RT52: VELOCITY-TIME GRAPHS—DISPLACEMENT

Graphs of velocity versus time during 4 seconds for identical objects are shown below. The objects move along a straight, horizontal surface under the action of a force exerted by an external agent.



Rank the magnitudes of the displacements of the objects during each of these intervals.

						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest							Least		

Explain your reasoning.

Answer: A = B = E > C = D = F.

The magnitude of the displacement is equal to the area under the graph (i.e., between, the line and the time axis) since these are graphs of velocity vs time. This area is zero in cases C, D, and F, because there is as much area above the time axis as below. In cases A, B, and E the magnitude of the area between the axis and the line is 4 meters, which is the magnitude of the displacement in these cases.

B1-WWT53: WALKING ROUND TRIP—AVERAGE SPEED

A student walks along a trail with a constant speed of 8 km per hour for 1 hour and then turns around and walks back to her starting point at a constant speed of 6 km per hour. She contends:

“My average speed was about 6.9 km per hour since I walked a total of 16 km in two and one-third hours time.”

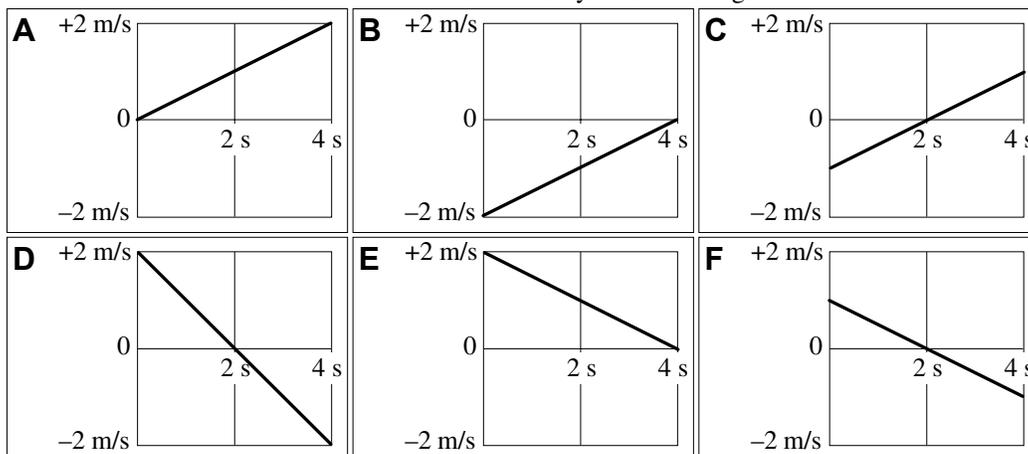
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The statement is correct.

Average speed is the distance traveled in some time interval divided by the time. In this case, the student walked 8 kilometers in the first hour and then turned around. To get back to where she started she traveled a total distance of 16 kilometers. Since on the return trip she was walking at 6 kilometers per hour, it took her one hour to return 6 kilometers, and one third of an hour to return the remaining 2 kilometers, for a total time of two and one-third hours. Dividing the total distance by the total time gives an average speed of 6.9 kilometers per hour.

B1-RT54: VELOCITY-TIME GRAPHS—ACCELERATION

Graphs of velocity versus time during 4 seconds for identical objects are shown below. The objects move along a straight, horizontal surface under the action of a force exerted by an external agent.



Rank the magnitudes of the accelerations of these objects during each of these intervals.

						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest									Least

Explain your reasoning.

Answer: $D > A = B = C = E = F$.

The magnitude of the acceleration is equal to the slope of the graph of velocity vs time.

B1-WWT55: ROUND TRIP UP A MOUNTAIN—AVERAGE SPEED

A student contends:

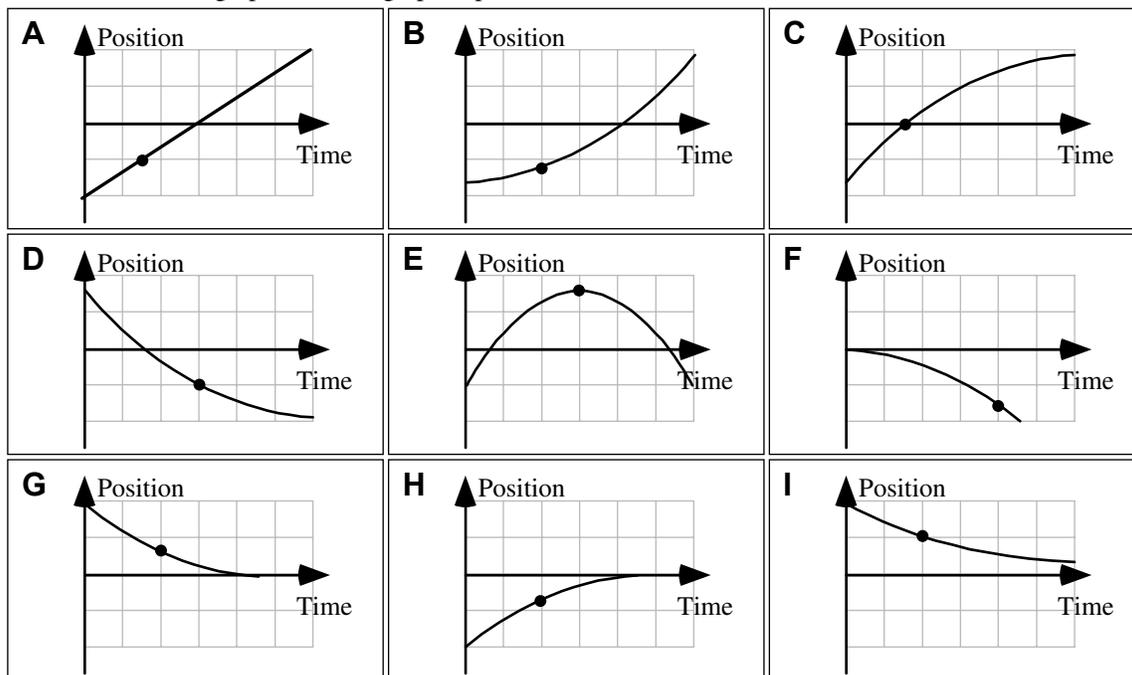
“If I climb up a mountain at 1 mile per hour for 2 hours and then turn around and climb back down at 3 miles per hour, then my average speed will be 2 miles per hour.

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: This statement is not correct. If it takes two hours to climb up the mountain at one mile per hour, the trip up the mountain must be two miles, and the round trip must be four miles. The trip down the mountain is two miles, and at three miles per hour it will take two thirds of an hour, or forty minutes. Average speed is the distance traveled in some time interval divided by the time. In this case, the four mile trip took two and two thirds hours, so the average speed is 1.5 miles per hour.

B1-QRT56: POSITION-TIME GRAPHS—ACCELERATION AND VELOCITY

Position versus time graphs for boats traveling along a narrow channel are shown below. The scales on both axes are the same for all of these graphs. In each graph, a point is marked with a dot.



(a) For which of these cases, if any, is the position zero at the indicated point?

Explain your reasoning.

Answer: The position is zero for the indicated point in graph C, which can be read directly off of the graph.

(b) For which of these cases, if any, is the position negative at the indicated point?

Explain your reasoning.

Answer: The position is negative for A, B, D, F, H.

(c) For which of these cases, if any, is the velocity zero at the indicated point?

Explain your reasoning.

Answer: The velocity is zero if the slope of the graph is zero at the indicated point, which is the case only for graph E.

(d) For which of these cases, if any, is the velocity negative at the indicated point?

Explain your reasoning.

Answer: The velocity is given by the slope of the position-time graph, and a negative velocity corresponds to a downward-sloping graph at the indicated point. Graphs D, F, G, and I have negative slopes at the indicated point.

(e) For which of these cases, if any, is the acceleration zero at the indicated point?

Explain your reasoning.

Answer: A zero acceleration corresponds to a constant velocity, which in turn corresponds to a linear position-time graph. The acceleration is zero for graph A.

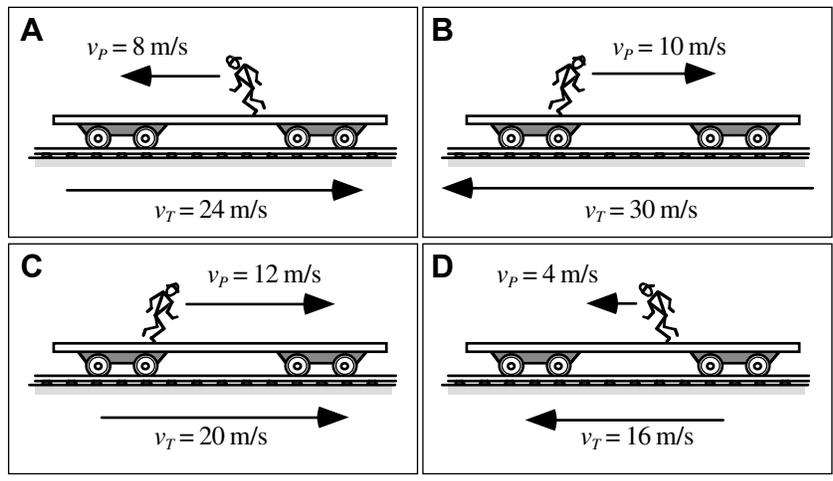
(f) For which of these cases, if any, is the acceleration negative at the indicated point?

Explain your reasoning.

A negative acceleration corresponds to a velocity graph whose slope is negative, which in turn corresponds to a position-time graph that curves downward (i.e., the slope becomes less positive or more negative with time). The accelerations are negative for graphs C, E, F, and H.

B1-RT57: PEOPLE ON TRAINS—SPEED RELATIVE TO GROUND

In each case shown, someone is running on a flatbed train car as the train moves. In cases C and D, the person is running toward the front of the train, while in cases A and B the person is running toward the rear. The speeds of the train and of each person relative to the train are given. An observer is standing beside the track watching each train go by.



Rank the speed of the runners relative to the observer standing beside the tracks.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

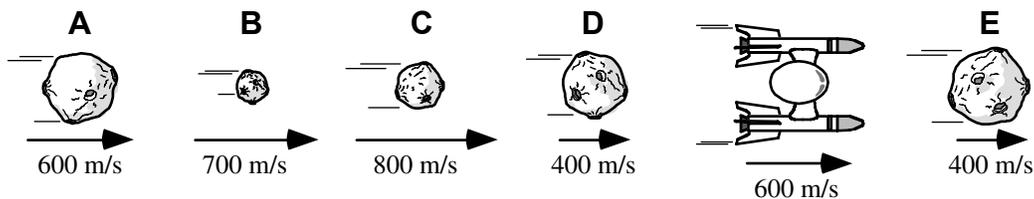
Explain your reasoning.

Answer: C > B = D > A.

The observer would see the runner moving at 32 m/s in C, 20 m/s in B and D, and 16 m/s in A.

B1-QRT58: MOVING ASTEROIDS NEAR SPACESHIP—VELOCITY DIRECTION

Shown are five asteroids and a spaceship, all moving in the same direction away from Earth. The velocities of the asteroids and of the spaceship are given as measured from Earth.



(a) List the asteroids that are moving toward the spaceship.

B and C and E

(b) List the asteroids that are moving away from the spaceship.

D.

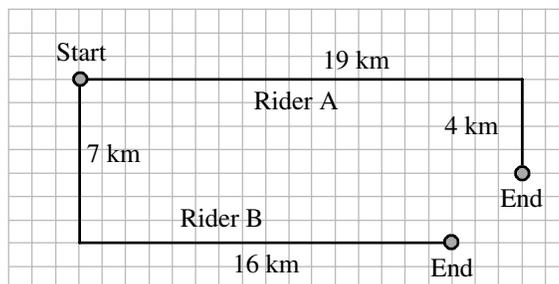
Explain your reasoning.

Asteroids D and E will be moving to the left at 200 m/s relative to an observer on the spaceship. Asteroid B will be moving to the right at 100 m/s relative to an observer on the spaceship. Asteroid A will be at rest relative to the spaceship. And asteroid C will be moving to the right at 200 m/s relative to the spaceship. The asteroids moving toward an observer on the spaceship are therefore B, C and E, and the one moving away from the observer is D.

B2 MOTION IN TWO DIMENSIONS

B2-CT01: MOTORCYCLE TRIPS—DISPLACEMENT

Shown below are the paths two motorcyclists took on an afternoon ride. Both started at the same place, and both took the same time for the ride. Rider A traveled east for 19 km and then south for 4 km. Rider B traveled south for 7 km and then east for 16 km.



(a) Is the magnitude of the displacement of the rider (i) *greater in case A*, (ii) *greater in case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: Even though the path lengths are the same for the two riders (23 km) the displacement is greater for Rider A because the diagonal distance is greater. Displacement is a vector quantity, and the length (magnitude) of the displacement is the straight line distance from the start point to the end point.

(b) Is the magnitude of the average velocity of the rider (i) *greater in case A*, (ii) *greater in case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: Since the displacement is greater for Rider A, because the diagonal distance is greater, Rider A's average velocity, which is displacement divided by elapsed time, has a greater magnitude also.

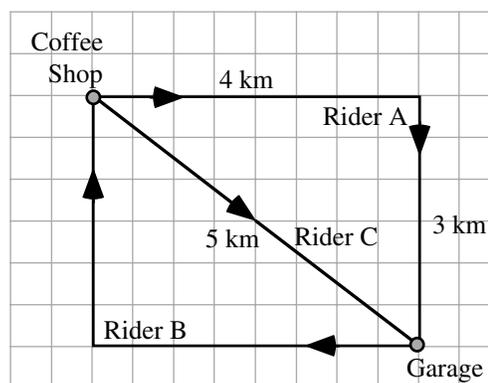
B2-SCT02: MOTORCYCLE TRIPS—DISPLACEMENT

The paths three motorcyclists took on an afternoon ride are shown. Riders A and C traveled from the coffee shop to the mechanic's garage along different paths, while Rider B traveled from the garage to the coffee shop. Three physics students discussing these rides make the following contentions:

Ali: "The lengths of the paths that Riders A and B travel are the same, so they have the same displacement. Rider C has the smallest displacement."

Bob: "I agree that Rider C has the smallest displacement, because the diagonal path is shortest. But the displacements of Riders A and B are actually different, because their directions are opposite each other."

Carol: "I think the displacements of all three riders are the same, because they go between the same two points. What path they follow doesn't matter."



With which, if any, of these three students do you agree?

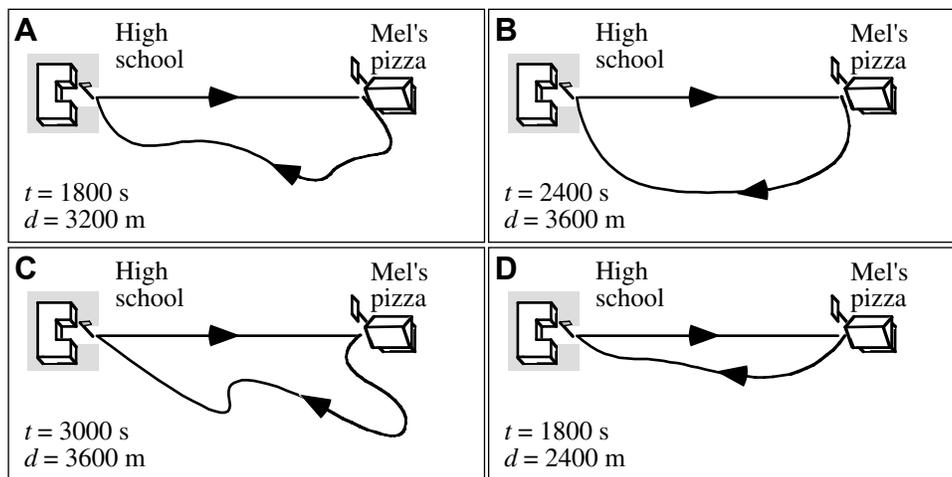
Ali _____ *Bob* _____ *Carol* _____ None of them _____

Explain your reasoning.

Answer: None of them are entirely correct. Bob is correct that the displacements of Riders A and B are opposite to each other, because the diagonal distance is the same with the starting and ending points reversed. But the displacements of Riders A and C are the same because they have the same start and end points.

B2-RT03: STUDENTS' JOURNEYS—AVERAGE VELOCITY

Four students went out for pizza to celebrate after acing their physics final. All of them went directly from their high school to the nearby pizzeria, but they returned along the paths shown, taking different times. Values for the round-trip distances they traveled and the total times they took to walk their routes are given in the figures.



Rank the magnitudes of the average velocities of the students' trips.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

Explain your reasoning.

Answer: All are zero.

Since the starting and ending points for all trips are the high school the displacements for all these roundtrips are zero regardless of the total distance traveled.

B2-SCT04: CAR ON A COUNTRY ROAD—AVERAGE SPEED AND VELOCITY

A car travels along a winding country road, speeding up and slowing down as it goes. The car ends up 30 km directly north of its starting point after 40 minutes of travel. Three students make the following contentions about this situation:

- Adnan: “I think if we calculated the average velocity and average speed for the car, the average velocity would have a larger value. The car moved in two dimensions, so the velocity, which is a vector, will be greater than the speed, which is a scalar quantity.”
- Bunmi: “I think the average speed will have a larger value than the average velocity. The road is not straight, so the distance traveled will be more than the displacement.”
- Cici: “I don’t see any reason the average velocity and average speed would have different values. They are just different names for the same thing.”

With which, if any, of these three students do you agree?

Adnan _____ Bunmi _____ Cici _____ None of them _____

Explain your reasoning.

Answer: Bunmi is correct.

The students are actually comparing the average speed to the magnitude of the average velocity. The distance traveled will be larger than the magnitude of the displacement, so the average speed being the distance divided by the elapsed time will be larger than the magnitude of the average velocity which is the magnitude of the displacement divided by the time.

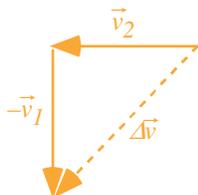
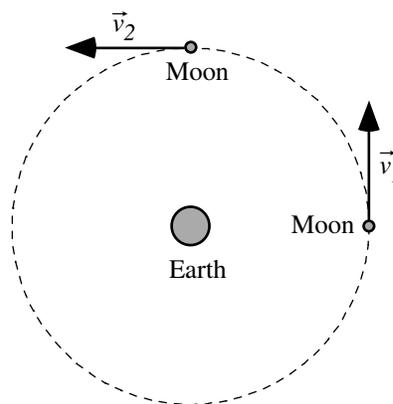
B2-QRT05: VELOCITY AND POSITION OF THE MOON—VELOCITY CHANGE DIRECTION

The position and velocity of the moon are shown at two times, about seven days apart.

Find the direction of the change in velocity of the moon in this time interval. If the change in velocity is zero, state that explicitly.

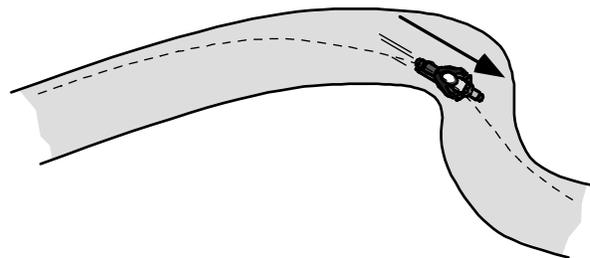
Explain your reasoning.

Answer: The change in velocity is found by subtracting the earlier velocity from the later velocity. The direction of the change in velocity is down and to the left.



B2-SCT06: MOTORCYCLE ON ROAD COURSE—ACCELERATION

A motorcycle is slowing down as it travels through a bend in a road. The path of the motorcycle is the dashed line shown in the bird's-eye view. The arrow represents the motorcycle's velocity at the instant shown. Three physics students make the following contentions about the acceleration of the motorcycle:



Alexi: “The motorcycle’s acceleration is in the opposite direction to the velocity since it is slowing down.”

Bindi: “No, the acceleration will have two components, one opposite the velocity and the other toward the center of the curve.”

Carlos: “I don’t think the motorcycle has an acceleration, since it is braking.”

With which, if any, of these three students do you agree?

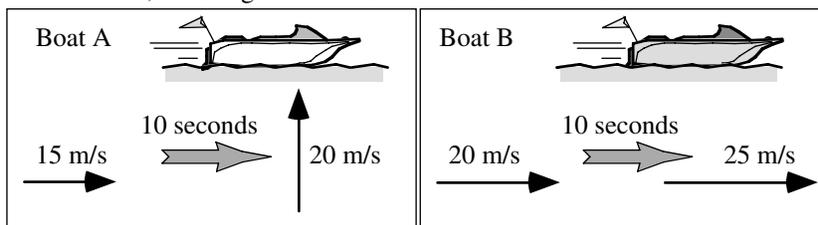
Alexi _____ Bindi _____ Carlos _____ None of them _____

Explain your reasoning.

Answer: Bindi is correct. Both the rate of motion and the direction of motion are changing. Since the motorcycle is slowing down, it will have an acceleration component in the direction opposite its motion, and since it is turning it will have an acceleration component perpendicular to the direction of motion toward the center of curvature.

B2-WWT07: SPEEDBOATS CHANGING VELOCITIES—ACCELERATION

Two speedboats are racing on a lake. In 10 seconds, Boat A goes from traveling east at 15 m/s to traveling north at 20 m/s. In the same time interval, Boat B goes from 20 m/s east to 25 m/s east.

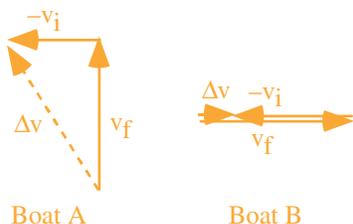


A student watching the race states:

“These two boats have the same acceleration for the 10-second interval since they both changed their velocities by 5 m/s in that time interval.”

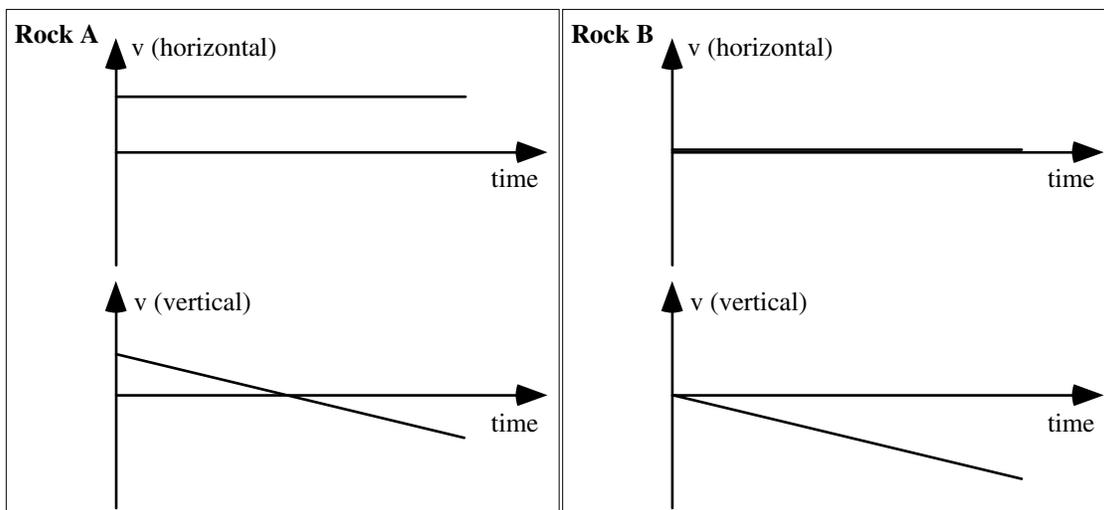
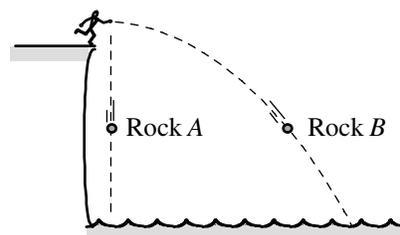
What, if anything, is wrong with this student’s contention? If something is wrong, identify it and explain how to correct it. If the contention is correct, explain why.

Answer: The student’s contention is wrong since he/she took the differences in the magnitudes of the velocities rather than the actual velocity differences for the interval. The acceleration for boat A will be directed at some angle to the northwest and will have a magnitude of 2.5m/s^2 (the length of the Δv vector, since it is the hypotenuse of a 3-4-5 right triangle) divided by 10 s, giving 2.5m/s^2 . Boat B’s acceleration is directed eastward and has a magnitude of 5 m/s divided by 10 s, giving 0.5m/s^2 .



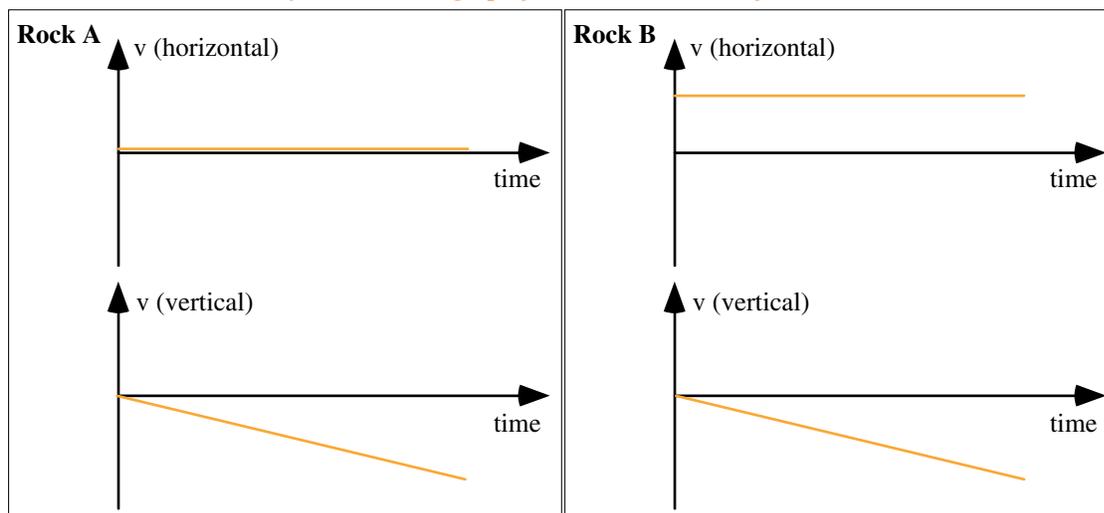
B2-WWT08: FALLING ROCK AND THROWN ROCK—VELOCITY-TIME GRAPHS

Rock A is dropped from the top of a cliff at the same instant that Rock B is thrown horizontally away from the cliff. The rocks are identical. A student draws the following graphs to describe part of the motion of the rocks, using a coordinate system in which the positive vertical direction is up, the positive horizontal direction is away from the cliff, and the origin of the coordinate system is the point the rocks were released from.



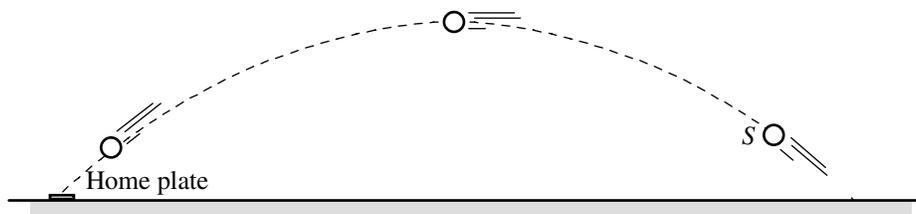
What, if anything, is wrong with these graphs for the motions of the two rocks? If something is wrong, identify it and explain how to correct it. If the graphs are correct, explain why.

The horizontal velocity graphs need to be switched, because Rock A has no horizontal velocity, and Rock B has a constant horizontal velocity. The vertical graph for Rock B is correct for both rocks.



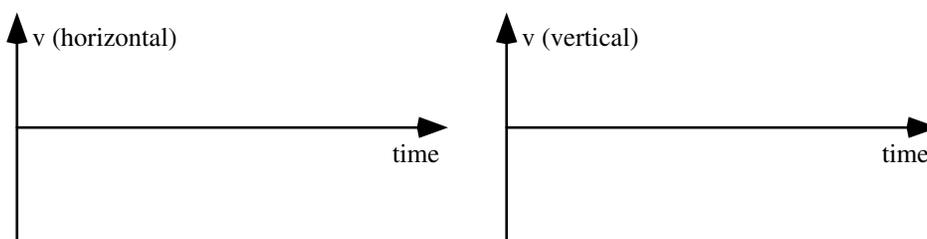
B2-QRT09: PROJECTILE MOTION—VELOCITY-TIME AND ACCELERATION-TIME GRAPHS

A baseball is thrown from point S in right field to home plate. The dashed line in the diagram shows the path of the ball. Use a coordinate system with up as the positive vertical direction and to the right as the positive horizontal direction, with the origin at the point the ball was thrown from (point S).



On the axes below, sketch graphs for the indicated quantities:

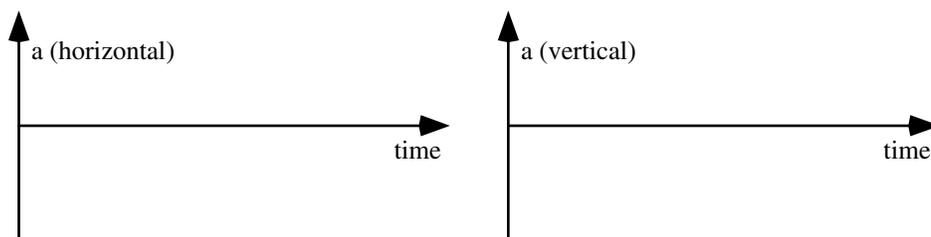
(a) The horizontal velocity versus time and the vertical velocity versus time.



Explain your reasoning.

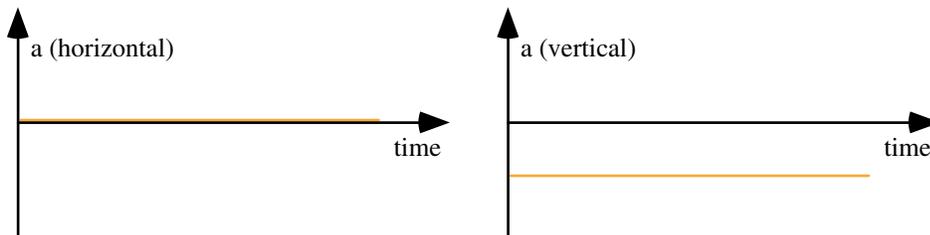
Answer: Since the positive horizontal direction is to the right, the horizontal velocity will be negative. Since up is the positive vertical direction the ball has a positive initial vertical velocity, which decreases to zero and then becomes negative.

(b) The horizontal acceleration versus time and the vertical acceleration versus time.



Explain your reasoning.

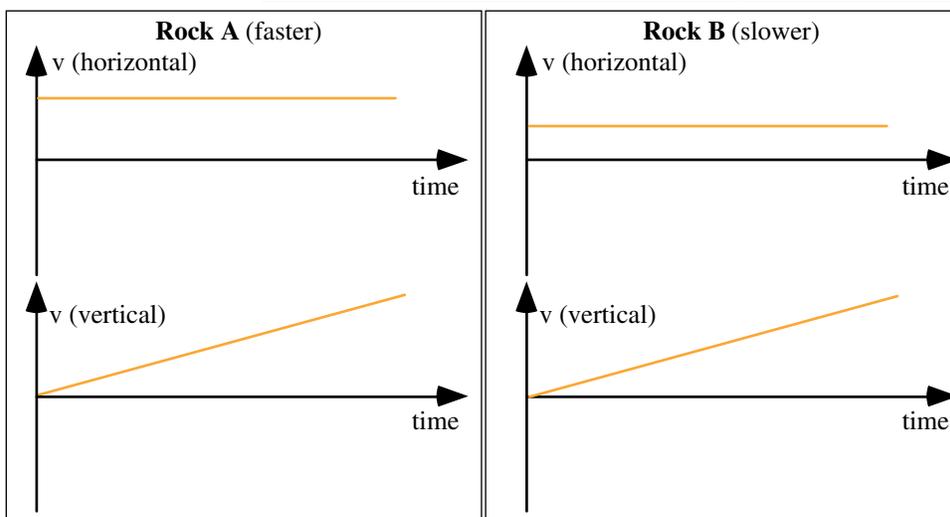
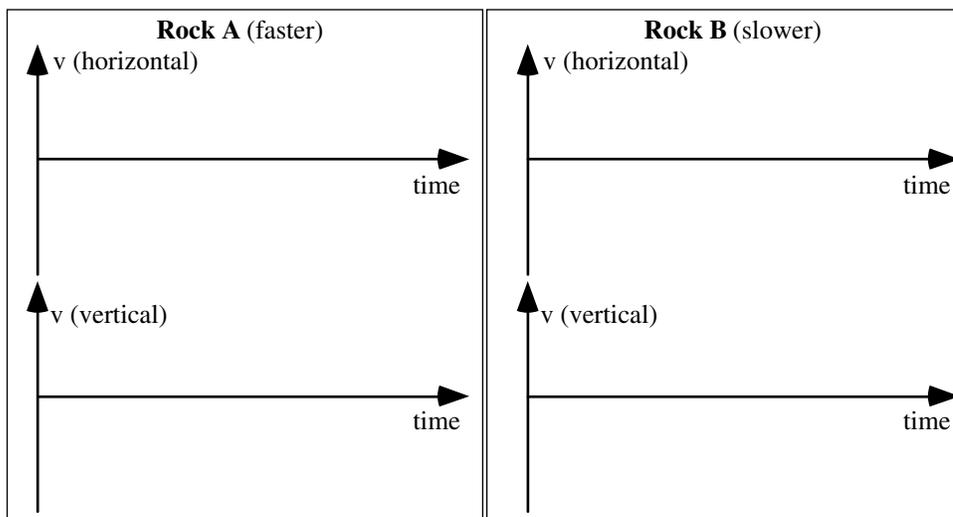
Answer: Since there is no force in the horizontal direction there will be no horizontal acceleration. The vertical acceleration is negative and equal in magnitude to g .



B2-QRT10: PROJECTILE MOTION FOR TWO ROCKS—VELOCITY-TIME AND ACCELERATION-TIME GRAPHS

Two identical rocks are thrown horizontally from a cliff, with Rock A having a greater velocity at the instant it is released than Rock B. Use a coordinate system with down as the positive vertical direction, away from the cliff as the positive horizontal direction, and with the origin of the coordinate system at the bottom of the cliff directly below the release point.

(a) Sketch the velocity versus time graphs for each of the rocks.



(b) Which rock hits the ground first?

Explain your reasoning.

Both hit at the same time. Both rocks have the same vertical acceleration and travel the same vertical distance.

(c) Which rock lands farthest from the base of the cliff?

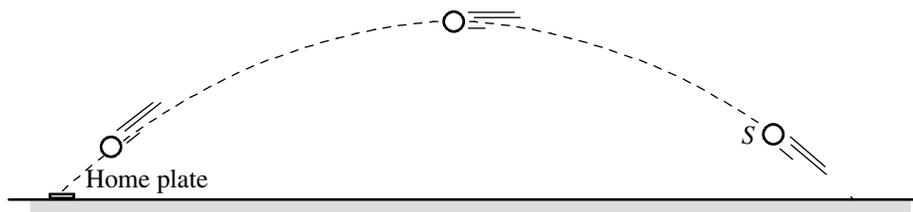
Explain your reasoning

Rock A, the faster rock.

There are no forces in the horizontal direction (ignoring air resistance) so both rocks will have a constant horizontal velocity. Since Rock B is slower than Rock A, it will have a smaller horizontal velocity. Both rocks are thrown horizontally, so they have no initial vertical velocity. Both are acted on by gravity, so the slopes of their vertical velocity graphs are constant and equal to g , and both are positive because gravity is acting down and the positive direction is defined as down. Both rocks hit at the same time but rock A hits farther from the cliff since it travels faster in the horizontal direction.

B2-QRT11: BASEBALL PROJECTILE MOTION—VELOCITY-TIME AND ACCELERATION-TIME GRAPHS

A baseball is thrown from point *S* in right field to home plate. The dashed line shows the path of the ball.



Use a coordinate system with up as the positive vertical direction and to the left as the positive horizontal direction, and with the origin at home plate.

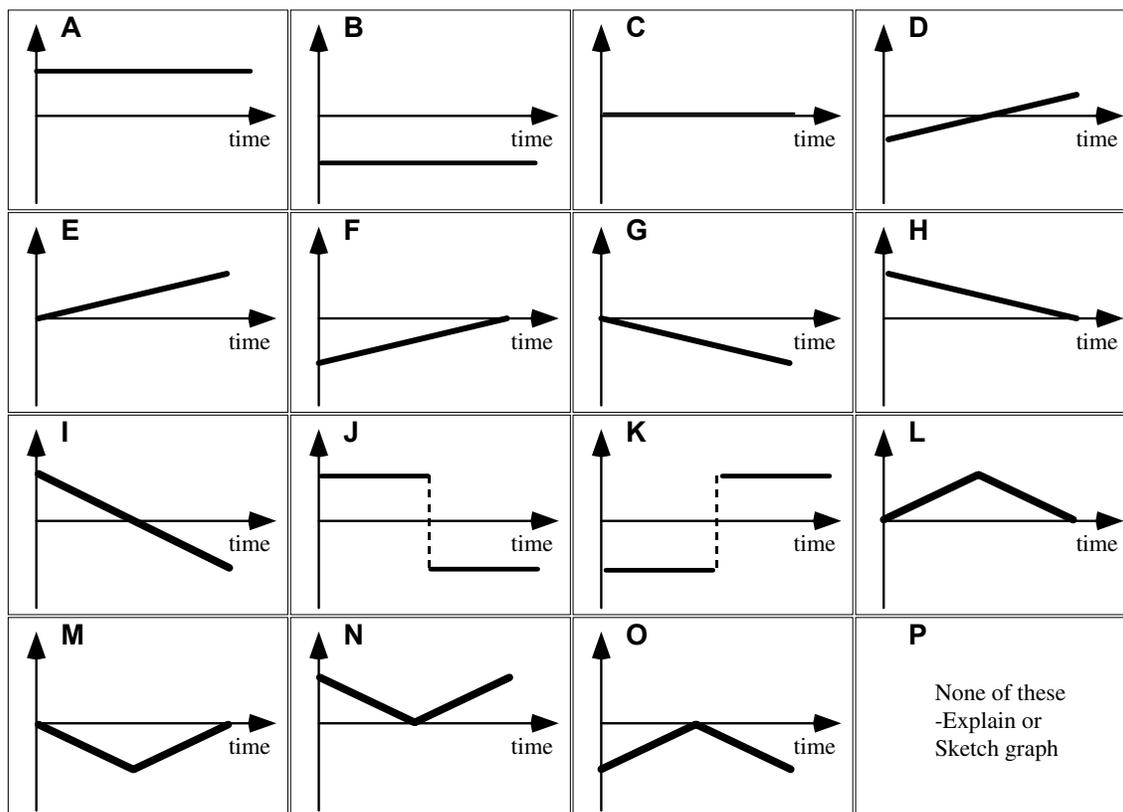
Select the graph from the choices below that best represents:

(i) horizontal velocity versus time graph ____ Explain your reasoning.

(ii) horizontal acceleration versus time graph ____ Explain your reasoning.

(iii) vertical velocity versus time graph ____ Explain your reasoning.

(iv) vertical acceleration versus time graph ____ Explain your reasoning.

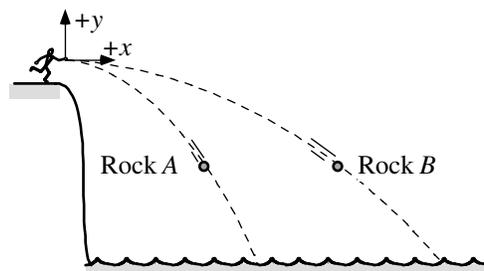


Answer: (1) A; (2) C; (3) I; and (4) B.

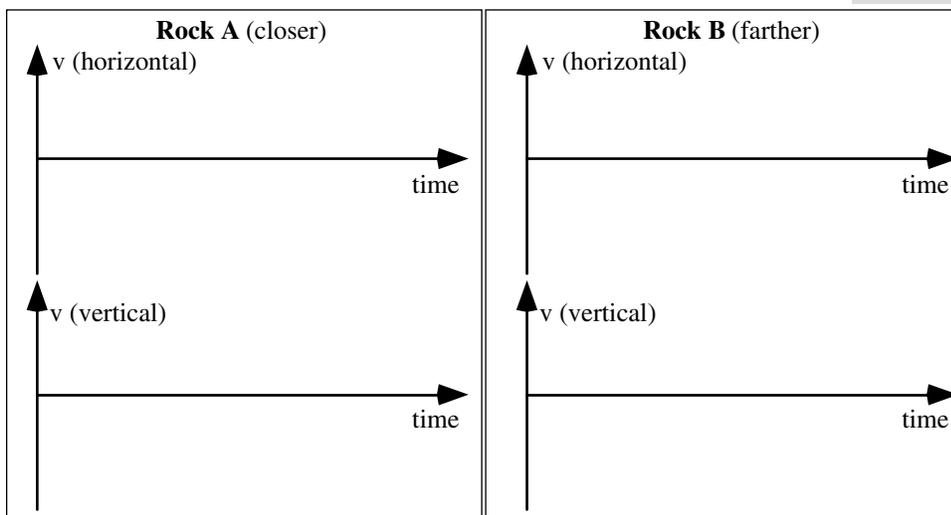
There are no horizontal forces (neglecting air resistance) and the ball will have no horizontal acceleration, so the horizontal velocity will be constant. The positive direction is to the left, so the horizontal velocity will be positive. Since up is positive, the initial vertical velocity is positive, and the final vertical velocity is negative. The only vertical force is gravity acting downward, and so the acceleration is constant, negative, and equal in magnitude to g . Since the acceleration is constant, the slope of the velocity must be constant, so the vertical velocity must be a straight line sloping downward from its initial positive value to its final negative value.

B2-CRT12: PROJECTILE MOTION FOR TWO ROCKS—VELOCITY-TIME GRAPHS

Two students throw two rocks horizontally from a cliff with different velocities. Both rocks hit the water below at the same time, but Rock B hits farther from the base of the cliff. Use coordinates where up is the positive direction, away from the cliff is the positive horizontal direction, and the origin is at the top of the cliff at the point of release.

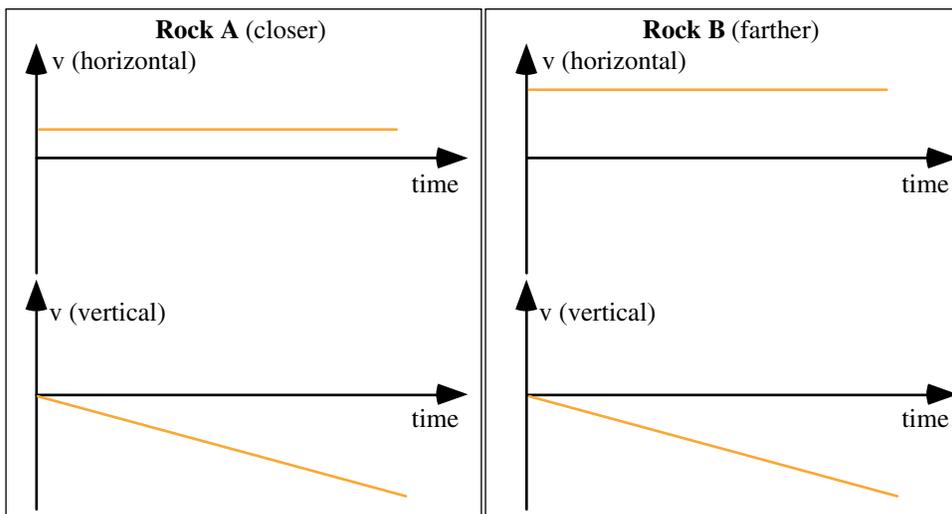


Sketch below the velocity versus time graphs for each rock.



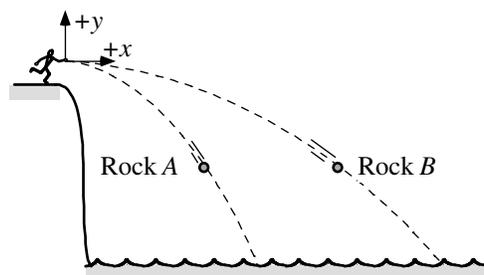
Explain your reasoning.

Answer: There are no forces in the horizontal direction (ignoring air resistance) so both rocks will have a constant horizontal velocity. Since Rock B lands farther away from the cliff than Rock A, it must have had a larger horizontal velocity. Both rocks are thrown horizontally, so they have no initial vertical velocity. Both are acted on by gravity, so the slopes of their vertical velocity graphs are constant equal to g , and both slopes are negative because gravity is acting down and the positive direction is defined as up.

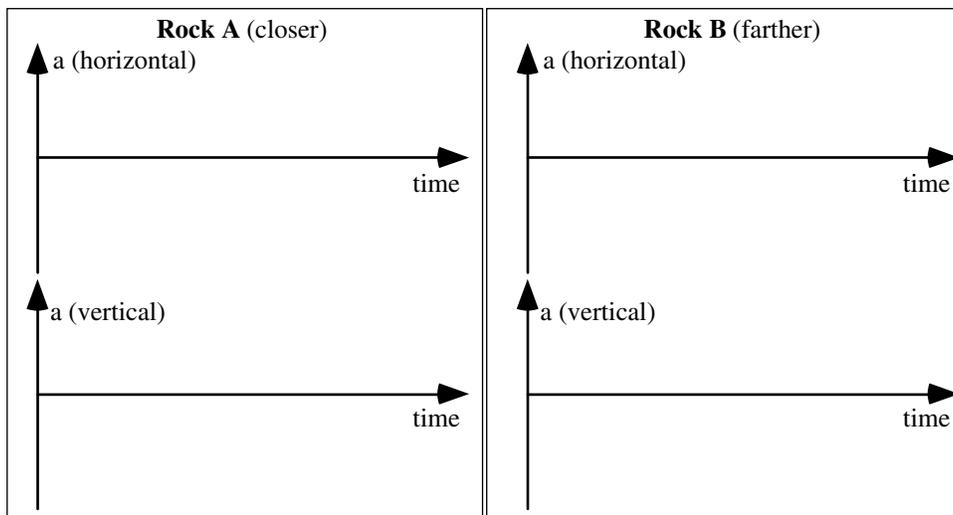


B2-CRT13: PROJECTILE MOTION FOR TWO ROCKS—ACCELERATION-TIME GRAPHS

Two students throw two rocks horizontally from a cliff with different velocities. Both rocks hit the water below at the same time, but Rock B hits farther from the base of the cliff. Use coordinates where up is the positive direction, away from the cliff is the positive horizontal direction, and the origin is at the top of the cliff at the point of release.

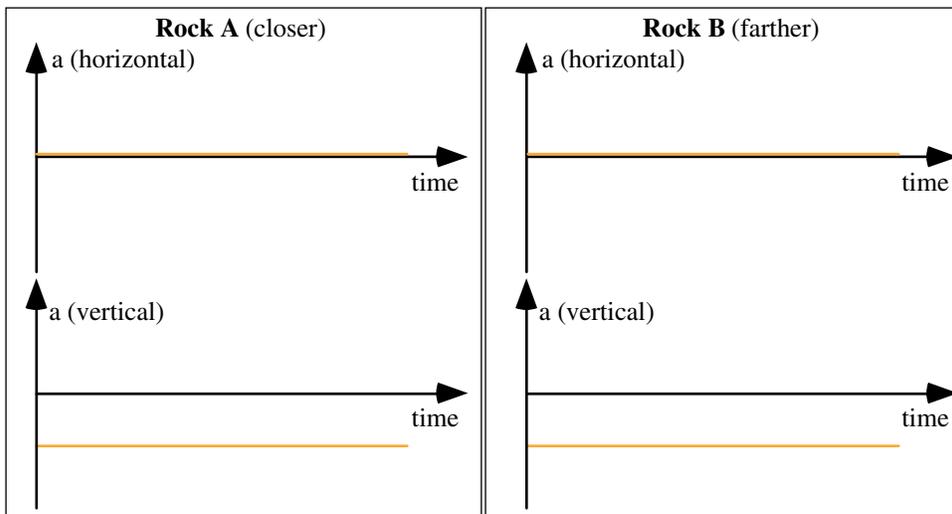


Sketch the acceleration versus time graphs for each rock.



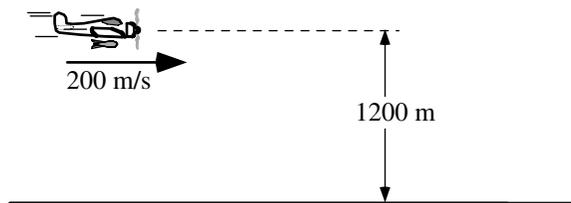
Explain your reasoning.

Answer: There are no forces in the horizontal direction (ignoring air resistance) so both rocks will have zero horizontal acceleration. Both are acted on by gravity, so both have a constant downward (negative, since the positive direction is defined as up) acceleration equal to g .



B2-LMCT14: DROPPED PRACTICE BOMB—HORIZONTAL DISTANCE TRAVELED

An airplane is flying 1200 m above the ground at a speed of 200 m/s. It drops a practice bomb that hits the ground after traveling a horizontal distance of 3130 m.



For each of the changes below, use the choices below (i)-(v) to identify what will happen to the horizontal distance the bomb travels while falling compared to the situation above.

- (i) The horizontal distance will be *greater than* 3130 m.
- (ii) The horizontal distance will be *less than* 3130 m but not zero.
- (iii) The horizontal distance will be *equal to* 3130 m.
- (iv) The horizontal distance will be *zero* (the bomb will drop straight down).
- (v) We *cannot determine* how this change will affect the horizontal distance.

For each of the following changes, only the feature(s) identified is(are) modified from the given situation above.

(a) The plane's speed is tripled. _____

Explain your reasoning.

A: The time it takes to hit the ground is the same, but the bomb has a greater horizontal velocity.

(b) The plane is climbing straight up at the release point. _____

Explain your reasoning.

D: Since there is no horizontal velocity it will come straight back down if it misses the plane.

(c) The plane is flying in level flight at an altitude of 1,100 m. _____

Explain your reasoning.

B: It will take less time to reach the ground from a lower height, and the horizontal speed is the same.

(d) The mass of the bomb is increased. _____

Explain your reasoning.

C: The vertical acceleration is still g and is independent of the mass, so the path the bomb takes will remain the same.

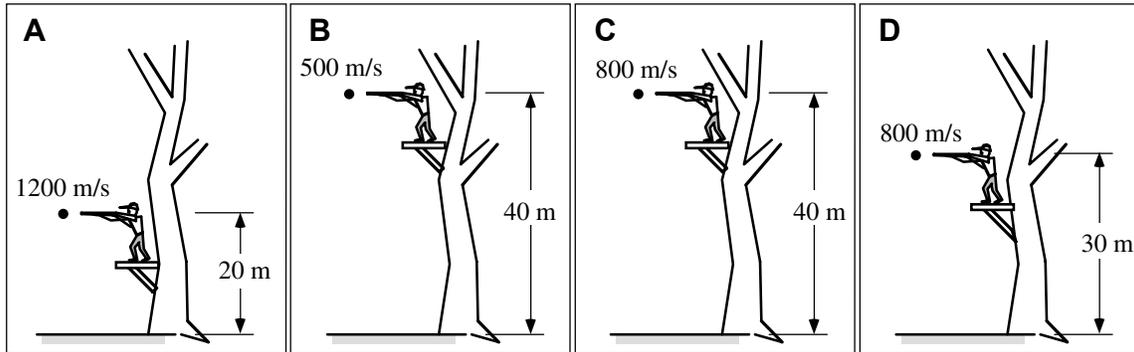
(e) The bomb is thrown from the plane with a vertical downward velocity of 15 m/s. _____

Explain your reasoning.

B: The acceleration of the bomb is the same, but with an initial downward vertical velocity it will reach the ground faster, and so will travel less horizontal distance.

B2-RT15: RIFLE SHOTS—TIME TO HIT GROUND

The rifles in the figures are being fired horizontally (straight outward, off platforms). The bullets fired from the rifles are all identical, but the rifles propel the bullets at different speeds. The speed of each bullet and the height of each platform are given. All of the bullets miss the targets and hit the ground.



Rank the time it takes the bullets to hit the ground.

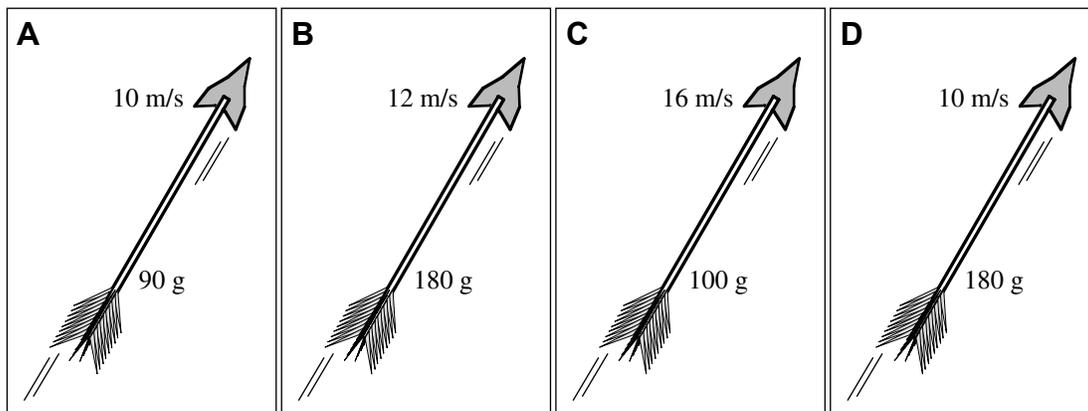
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer B = C > D > A. Motions along axes which are perpendicular to each other are independent of each other. The time in the air is determined by the time it takes the bullet to fall from the heights of the platforms in the vertical direction. Since all of the bullets start from rest in the vertical direction and have the same acceleration, that due to the gravitational force, the time in air is determined by the heights of the platforms.

B2-RT16: ARROWS—MAXIMUM HEIGHTS

All of the arrows shown were shot from the same height and at the same angle. Though the arrows have the same size and shape, they are made of different materials, so they have different masses, and they have different speeds as they leave the bows.



Rank the maximum heights the arrows reach.

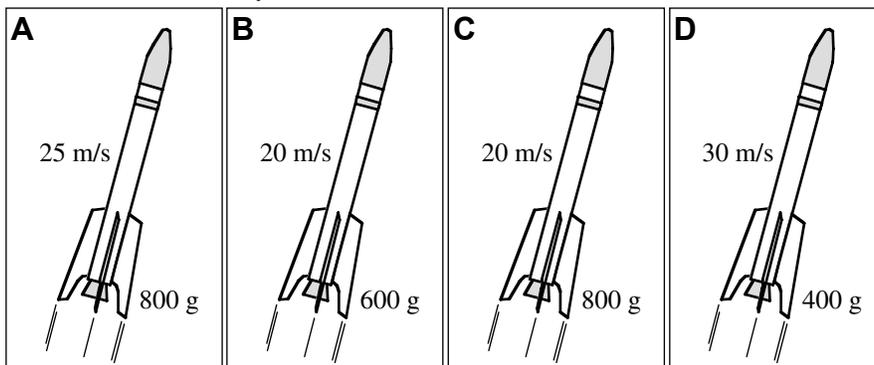
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer C > B > A = D. Since all of these arrows are subject to the gravitational force of the Earth, which is the same no matter what the mass of the object, the only factor determining the maximum height is the vertical

B2-RT17: MODEL ROCKETS FIRED AT AN ANGLE—HORIZONTAL SPEED AT TOP

The six model rockets shown are all at the same height and have just had their engines turned off. All of the rockets are aimed upward at the same angle, but their speeds differ. Though the rockets are all the same size and shape, they carry different loads, so their masses vary.



Rank the horizontal speed of the rockets at the top (at the maximum height).

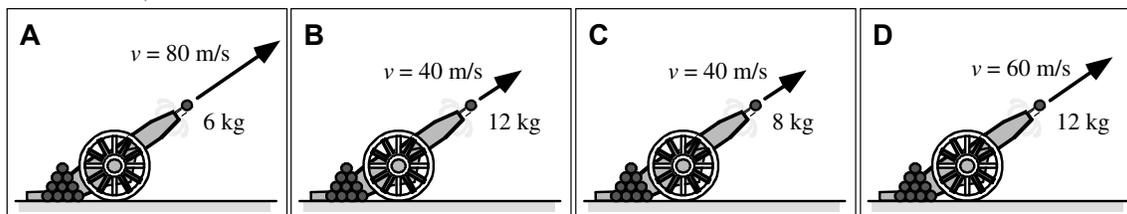
				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

Explain your reasoning.

Answer $D > A > B = C$. Since all of these rockets are subject to the gravitational force of the Earth, which is the same no matter what the mass of the object, the only factor determining the maximum height is the vertical component of the velocity at the given point. Since they all have the same angle relative to the horizontal, we can use the speed at the given point to determine the rankings.

B2-RT18: CANNONBALLS—ACCELERATION AT THE TOP

All of the cannons in the figures are identical, and all are aimed at the same angle of 35 degrees to the horizontal. The cannonballs are all the same size and shape, but the masses of the cannonballs, as well as their speeds as they leave the cannons, are different.



Rank the acceleration of the cannonballs when they reach their highest point.

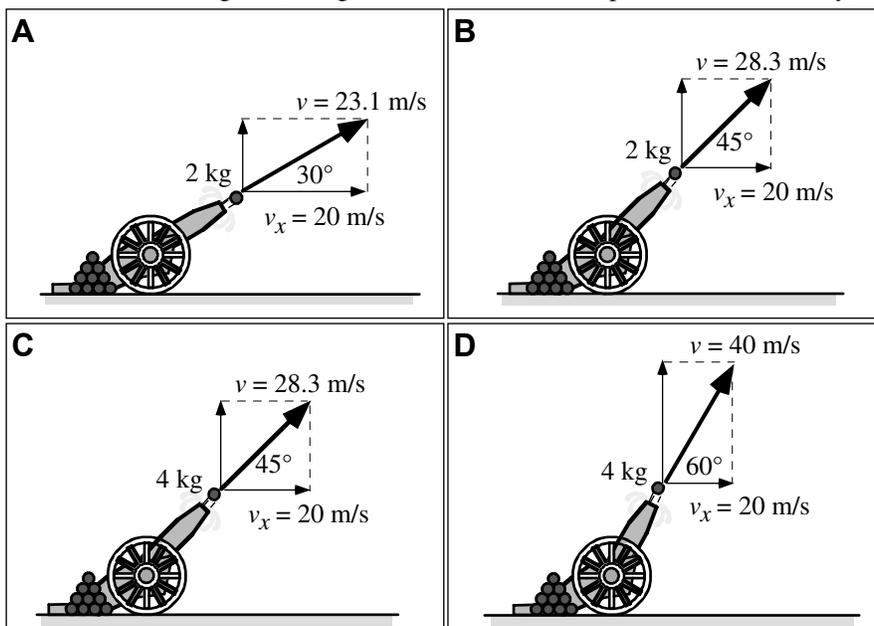
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: All the same. All of the cannonballs are subject to a net force due to the gravitational force of the earth which does not depend on mass, so all of the balls have the same acceleration throughout their motion, and this includes at the top.

B2-RT19: CANNONBALLS—HORIZONTAL DISTANCE

Cannonballs of different masses are shot from cannons at various angles above the horizontal. The velocity of each cannonball as it leaves the cannon is given, along with the horizontal component of that velocity, which is the same.



Rank the horizontal distance traveled by the cannonballs.

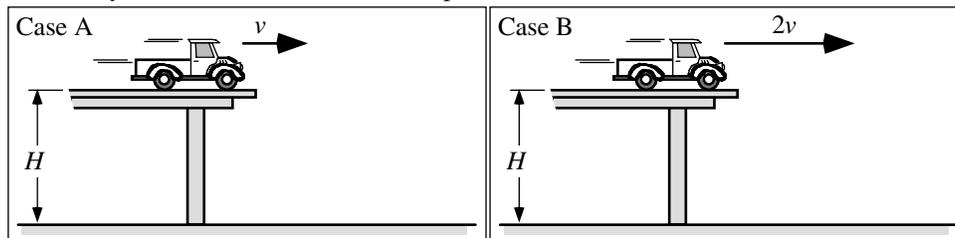
<input style="width: 100%; height: 20px;" type="text"/>	OR	<input style="width: 100%; height: 20px;" type="text"/>	<input style="width: 100%; height: 20px;" type="text"/>	<input style="width: 100%; height: 20px;" type="text"/>			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: $D > C = B > A$. The horizontal distance is based on $x_f = v_o (\cos \theta) t_f$. Thus, the range, as x_f is sometimes called, is determined by the initial speed, the angle, and the time of flight. As stated in the problem and in the diagrams, the horizontal component of the velocity ($v_o \cos \theta$) is the same value for all six cases, 20 m/s. So, the range for this ranking task is determined by the time of flight, t_f . The time of flight is determined by the y-component of the initial velocity (since for all cases the cannonballs start and end at the same height). Hence, the larger the y-component of the initial velocity, the longer the cannonball will be in the air and the larger its range

B2-WWT20: HORIZONTALLY LAUNCHED TOY TRUCKS—TIME IN AIR I

A toy truck is launched horizontally from a table of height H . In Case A, the toy truck leaves the table with a speed v , and in Case B the toy truck leaves the table with a speed $2v$.



A student comparing the time the trucks are in the air in these cases states:

“The faster you go, the less time it takes to get there. The truck in Case A will be in the air longer.”

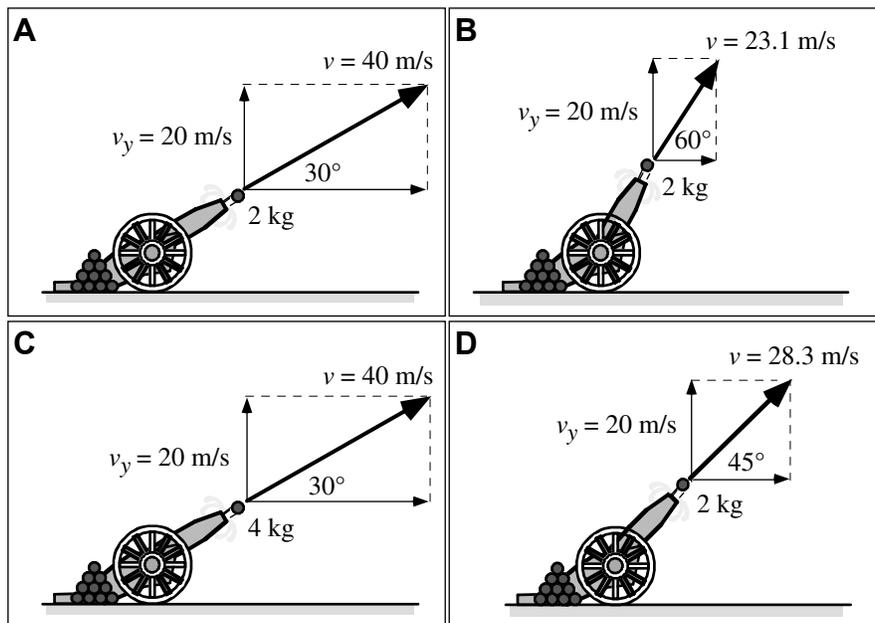
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student’s statement is incorrect.

If two objects are traveling the same distance, then it is true that the object that travels with the greatest speed will take the least time. In this case, however, the toy truck in case B is will travel a greater horizontal distance while in the air, because it was launched with a greater speed. Both

B2-RT21: CANNONBALLS—TIME IN AIR

Cannonballs with different masses are shot from cannons at various angles above the horizontal. The velocity of each cannonball as it leaves the cannon is given, along with the same vertical component of that velocity.



Rank the time the cannonballs are in the air.

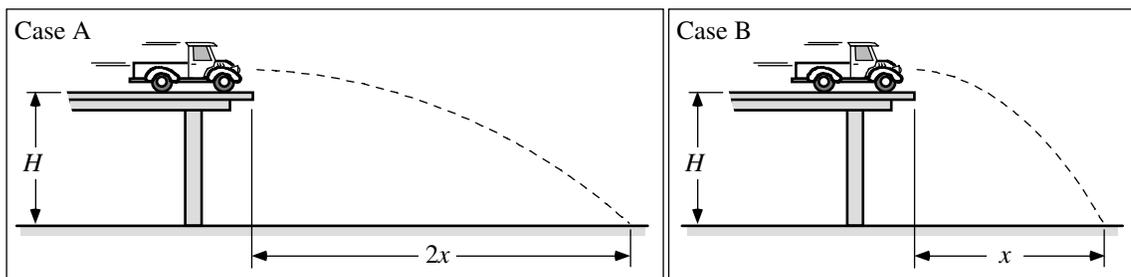
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: All the same. The time in the air is determined by the vertical component of the velocity because it will be the sum of the time the ball takes to get to the top of its trajectory plus the time back down to the ground. Since these cannon balls are all fired from ground and return to ground the time in the air will be twice the time up to the top of the trajectory. Since all of these cases have the same vertical component of the velocity and the same vertical acceleration of 9.8 m/s^2 they will all take the same time.

B2-WWT22: HORIZONTALLY LAUNCHED TOY TRUCKS—TIME IN AIR II

A toy truck is launched horizontally from a table. In Case A the toy truck hits the floor a horizontal distance $2x$ from the edge of the table, and in Case B the toy truck hits the floor a horizontal distance x from the table.



A student comparing the time the trucks are in the air in these cases states:

“The farther you go, the longer it takes to get there. The truck in Case A will be in the air longer.”

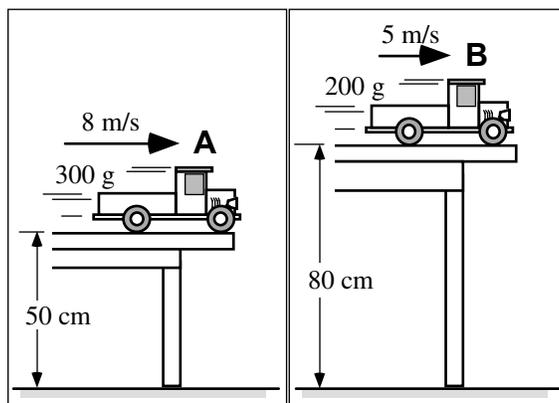
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's statement is incorrect.

If two objects are traveling with the same speed, then it is true that the object that travels the longest distance will take the most time. In this case, however, the toy truck in case A is in the air just as long as the truck in case B, since they both travel the same vertical distance with the same acceleration, but the truck in case A has the larger horizontal speed.

B2-CT23: TOY TRUCKS ROLLING FROM TABLES WITH DIFFERENT HEIGHTS—TIME

Two toy trucks roll off the ends of tables. The heights of the tables, the speeds of the trucks, and the masses of the trucks are given.



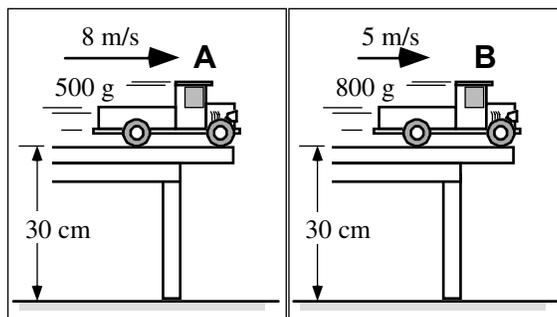
Will Truck A be in the air for (i) a longer time, (ii) a shorter time, or (iii) the same time as Truck B before it reaches the floor? _____

Explain your reasoning.

Answer: a shorter time because it has a smaller distance to fall. Both trucks are acted on by gravity, so they will both accelerate downward with the same acceleration g . Both trucks have no initial vertical velocity. The time they are in the air depends only on initial height. Mass and horizontal velocity don't affect the time the trucks are in the air.

B2-CT24: TOY TRUCKS WITH DIFFERENT SPEEDS ROLLING FROM IDENTICAL TABLES—TIME

Two toy trucks roll off the ends of identical tables. The speeds and masses of the trucks are given.



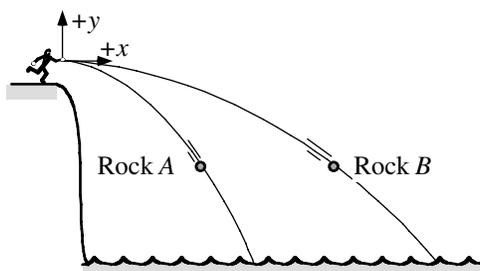
Will Truck A be in the air for (i) a longer time, (ii) a shorter time, or (iii) the same time as Truck B before it reaches the floor? _____

Explain your reasoning.

Answer: the same time because they have the same distance to fall. Both trucks are acted on by gravity, so they will both accelerate downward with the same acceleration g . Both trucks have no initial vertical velocity. The time they are in the air depends only on initial height. Mass and horizontal velocity don't affect the time the trucks are in the air.

B2-CT25: PROJECTILE MOTION FOR TWO ROCKS—VELOCITY AND ACCELERATION

Two identical rocks are thrown horizontally from a cliff with different velocities. The rocks are thrown at the same time and are shown below while they are still in the air after a few seconds.



For the instant shown:

(a) Will the magnitude of the horizontal velocity of Rock A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the horizontal velocity of Rock B? _____

Explain your reasoning.

Answer: less, since the picture shows Rock A lands closer to the cliff than Rock B and thus the horizontal velocity of Rock A is smaller than Rock B

(b) Will the magnitude of the vertical velocity of Rock A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the vertical velocity of Rock B? _____

Explain your reasoning.

Answer: equal, due to both being released with zero vertical velocity and having the same downward acceleration.

(c) Will the magnitude of the horizontal acceleration of Rock A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the horizontal acceleration of Rock B? _____

Explain your reasoning.

Answer: equal, both have zero horizontal acceleration since we are ignoring air friction.

(d) Will the magnitude of the vertical acceleration of Rock A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the vertical acceleration of Rock B? _____

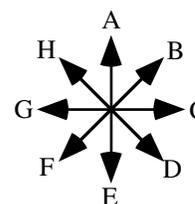
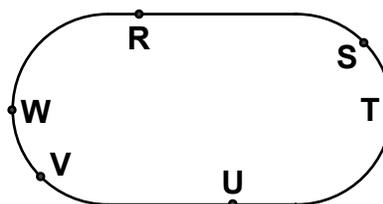
Explain your reasoning.

Answer: equal, due to the fact that both have the same acceleration of gravity.

B2-QRT26: CONSTANT SPEED CAR ON OVAL TRACK—ACCELERATION AND VELOCITY DIRECTIONS

A car travels clockwise at a constant speed around an oval track.

In the table below, indicate the direction of the velocity and acceleration of the car for the labeled points. Use the direction labels in the rosette at the far right: **J** for no direction, **K** for into the page, **L** for out of the page, or **M** if none of these are correct.



Point on track	Velocity direction	Acceleration direction
R		
S		
T		
U		
V		
W		

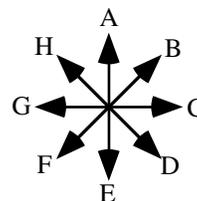
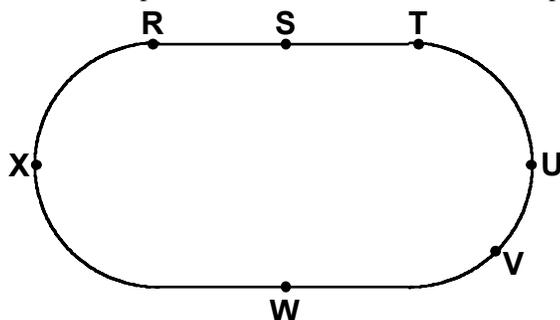
Explain your reasoning.

Answer: The velocity of the car is tangent to the path at each point in the direction of motion. The car's velocity points to the right at point R and the speed is constant so the acceleration is zero. At S the velocity is directed toward D, but its direction is changing so the acceleration is directed toward F. The situation is similar at T with the velocity directed toward E and the acceleration, which has to be perpendicular to the velocity since only the direction is changing, is directed toward G. For point U the velocity is tangent to the track the acceleration is zero. For point V the velocity is tangent to the track pointing toward H, and the acceleration is perpendicular to this, pointing toward B. At point W the velocity is directed toward A and the acceleration is directed toward C.

Point on track	Velocity direction	Acceleration direction
R	C	J
S	D	F
T	E	G
U	G	J
V	H	B
W	A	C

B2-QRT27: CAR ON OVAL TRACK—DIRECTION OF THE ACCELERATION AND VELOCITY

A car on an oval track starts from rest at point R and moves clockwise around the track. It increases its speed at a constant rate until it reaches point T and then travels at a constant speed until it returns to point R.



In the table below, give the direction of the velocity and acceleration of the car at the indicated points. Use the direction labels in the rosette to the right of the racetrack drawing: J for no direction, K for into page, L for out of page, or M if none of these are correct.

Point on track	Velocity direction	Acceleration direction
S		
U		
V		
W		
X		

Explain your reasoning.

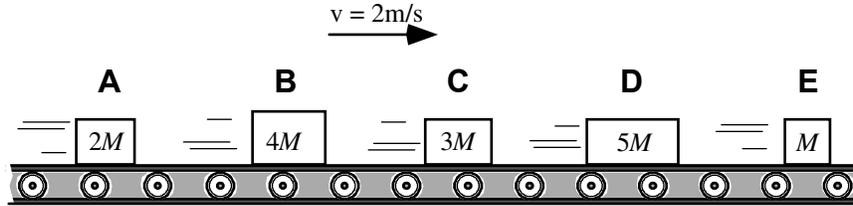
The car’s velocity points to the right between points R and T, and since the speed is increasing the acceleration also points to the right. From point T to the bottom of the semicircle it is moving at a constant speed in a circle, so there is only a centripetal acceleration pointing to the inside of the track and perpendicular to the velocity. For point U the velocity is tangent to the track and points down, and the acceleration is to the left. For point V the velocity is tangent to the track pointing down and to the left, and the acceleration is perpendicular to this, pointing up and to the left. At point W the velocity is to the left but since the car is not speeding up, slowing down, or changing directions there is no acceleration. Finally, at point X the velocity is tangent to the track pointing up, and the acceleration is centripetal only, pointing to the right.

Point on track	Velocity direction	Acceleration direction
S	<i>C</i>	<i>C</i>
U	<i>E</i>	<i>G</i>
V	<i>F</i>	<i>H</i>
W	<i>G</i>	<i>J</i>
X	<i>A</i>	<i>C</i>

B3 NEWTON'S LAWS

B3-RT01: PACKAGES MOVING ON A CONVEYOR BELT—NET FORCE

Various packages with different masses are moving on a constant-speed conveyor belt. At the instant shown below, all packages have the same constant velocity of 2 m/s directed to the right. The packages do not slip on the belt. All masses are given in the diagram in terms of M , the mass of the smallest package.



Rank the magnitude of the net force on each package.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>				
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

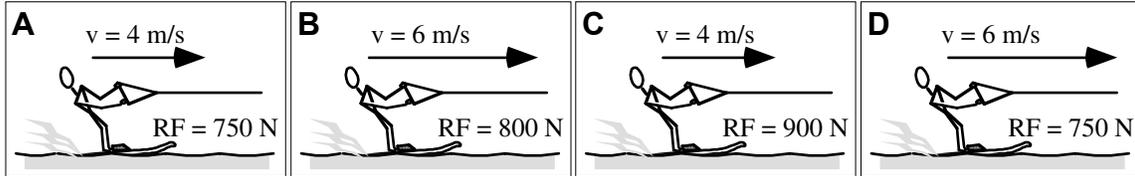
Explain your reasoning.

Answer: All Zero.

The net force on each package must be zero due to Newton's 1st Law since they are not accelerating (moving at a constant speed).

B3-RT02: WATER SKIERS—NET FORCE

Water skiers are pulled at a constant speed by a towrope attached to a speedboat. Because the weight of the skiers and the type of skis they are using varies, they experience different resistive forces from the water. Values for this resistive force (RF) and for the speed of the skiers are given.



Rank the magnitude of the net force on each water skier.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

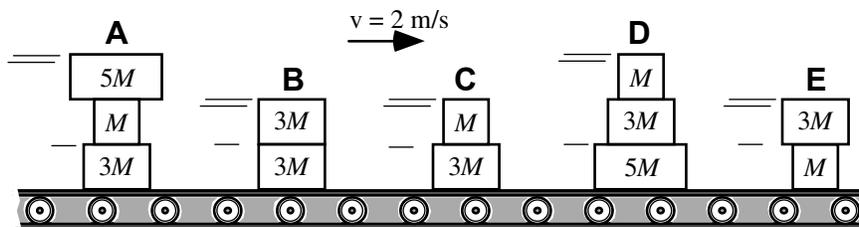
Explain your reasoning.

Answer: All Zero.

The net force on each skier must be zero due to Newton's 1st Law since they are not accelerating.

B3-RT03: STACKED PACKAGES MOVING ON MOVING CONVEYOR BELT—NET FORCE

Various stacks of packages are traveling along a conveyor belt. At the instant shown below, all packages have the same velocity of 3 m/s to the right. The packages do not slip on the belt. All masses are given in the diagram in terms of M , the mass of the smallest package.



Rank the magnitude of the net force on each stack of packages.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>				
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

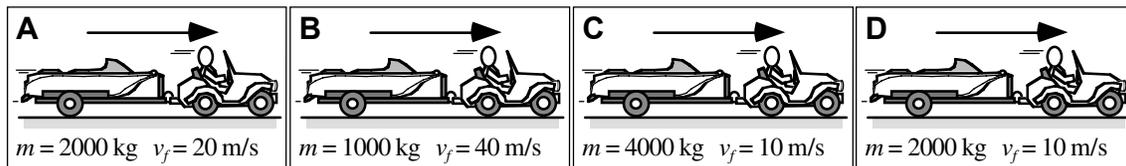
Explain your reasoning.

Answer: All Zero

Each stack moves at a constant velocity and Newton's 1st Law states the net force will be zero.

B3-RT04: MOVING CAR WITH BOAT TRAILER—NET FORCE ON BOAT TRAILER

All the trailers and cars shown are identical, but the boat trailers have different loads. In each case, the car and boat trailer are moving at the constant speed shown.



Rank the magnitude of the net force on each boat trailer.

<input style="width: 100%; height: 100%;" type="text"/>	OR	<input style="width: 100%; height: 100%;" type="text"/>	<input style="width: 100%; height: 100%;" type="text"/>	<input style="width: 100%; height: 100%;" type="text"/>			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

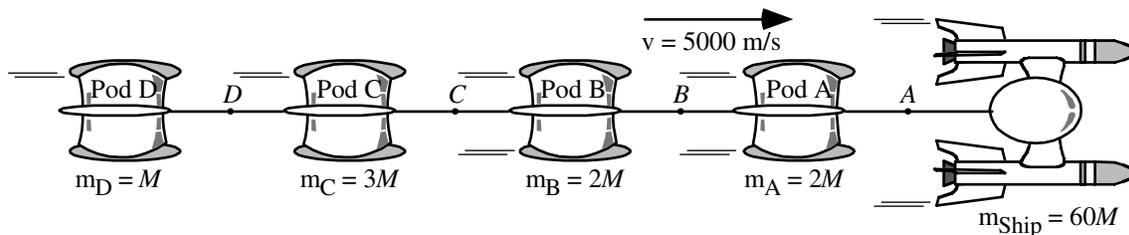
Explain your reasoning.

Answer: All Zero

Each boat trailer moves at a constant velocity and Newton's 1st Law states the net force will be zero.

B3-RT05: MOVING SPACESHIP WITH FOUR CARGO PODS—TENSION IN RODS

A spaceship and four cargo pods are connected together by rods, and they are all moving at a constant velocity of 5000 m/s. All masses are given in the diagram in terms of M , the mass of an empty pod.



Rank the tension at the labeled points in the rods.

1	2	3	4	OR	All	All	Cannot
Greatest			Least	the same	zero	determine	

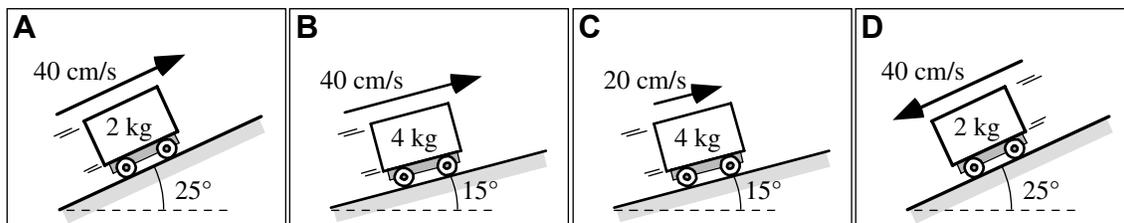
Explain your reasoning.

Answer: Tensions in the rods are all zero.

Since the velocity of each pod is constant, there is no acceleration and therefore no net force on any of the vehicles. For the net force to be zero for each pod, the tension in all rods must be zero.

B3-RT06: CARTS ON INCLINES—NET FORCE

Carts that have a motor and brakes are traveling either up or down inclines at constant speeds. The carts are identical but they carry either a 2 kg or 4 kg load and are on one of two inclines. Incline angles, cart masses, and speeds are given in each figure.



Rank the magnitude of the net force acting on the cart.

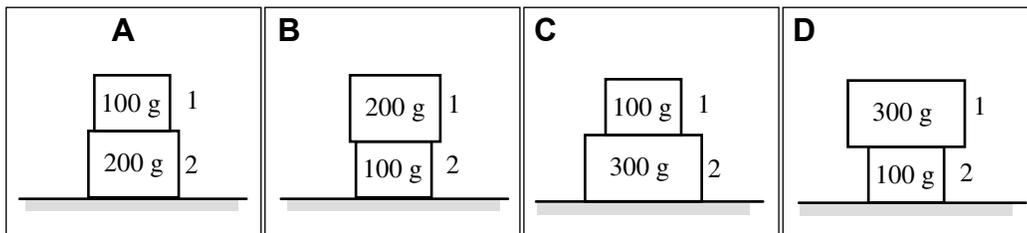
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: The net force is zero for all of these cases since the carts have constant velocities and therefore no accelerations.

B3-RT07: TWO STACKED BLOCKS AT REST—NET FORCE ON THE BOTTOM BLOCK

Two wooden blocks with different masses are at rest, stacked on a table. The top block is labeled **1**, and the bottom block is labeled **2**.



Rank the magnitude of the net force on the bottom block (2).

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

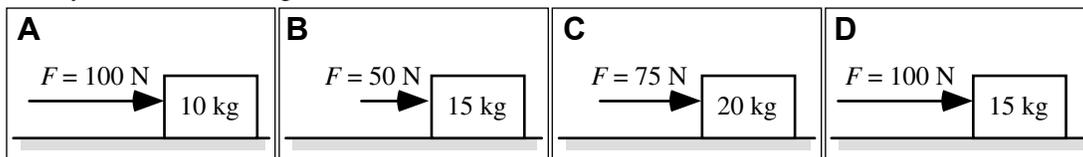
Explain your reasoning.

Answer: All Zero.

The net force on each block must be zero due to Newton's 1st Law since they are not accelerating.

B3-RT08: FORCE PUSHING BOX—ACCELERATION

Various similar boxes are being pushed for 10 m across a floor by a net horizontal force as shown below. The mass of the boxes and the net horizontal force for each case are given in the indicated figures. All boxes have the same initial velocity of 10 m/s to the right.



Rank the acceleration of the boxes.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest							Least

Explain your reasoning.

Answer: A > D > C > B

The acceleration equals the net force on each box divided by the mass of the block or $a = F_{net}/m$ using Newton's 2nd Law. For A, $a = F_{net}/m = 100\text{ N}/10\text{ kg} = 10\text{ m/s}^2$; for B, $a = F_{net}/m = 50\text{ N}/15\text{ kg} = 3.33\text{ m/s}^2$; for C, $a = F_{net}/m = 75\text{ N}/20\text{ kg} = 3.75\text{ m/s}^2$; and for D, $a = F_{net}/m = 100\text{ N}/15\text{ kg} = 6.67\text{ m/s}^2$

B3-CT09: BLOCKS IN MOVING ELEVATORS—STRETCH OF SPRING

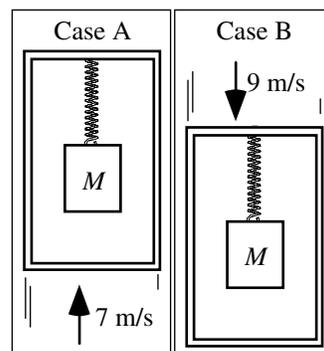
A spring is attached to the ceiling of an elevator, and a block of mass M is suspended from the spring. The cases are identical except that in Case A the elevator is moving upward with a constant speed of 7 m/s, while in Case B the elevator is moving downward with a constant speed of 9 m/s.

Will the spring be stretched (i) *more* in Case A, (ii) *more* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

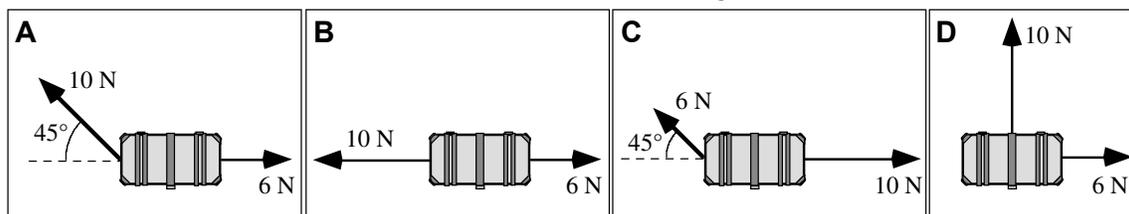
Answer: The same in both cases.

In both cases the block is moving with a constant velocity, so the net force on the block is zero. Since the only forces acting on the block are the weight of the block and the force from the spring, these forces must be equal in magnitude and opposite in direction to give zero net force. Since the weight of the block is the same in case A as in case B, the force by the spring must be the same also, and therefore the springs are stretched the same amount.



B3-RT10: TWO-DIMENSIONAL FORCES ON A TREASURE CHEST—FINAL SPEED

Identical treasure chests (shown from above) each have two forces acting on them. All chests start at rest.



Rank the speed of the treasure chest after 2 seconds.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

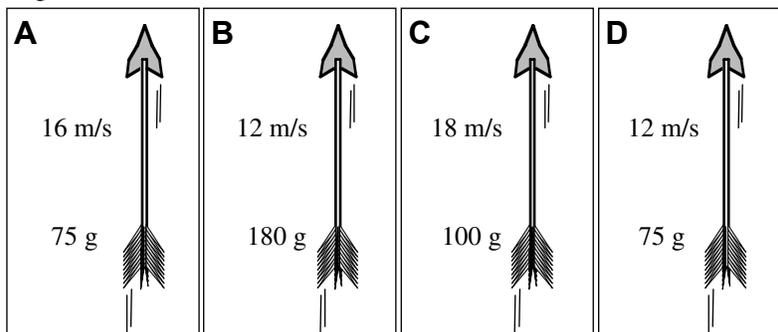
Explain your reasoning.

Answer: D > C = A > B.

We need to find the accelerations of the chests. Since they are all starting from rest and accelerating for the same time, the final speed will be proportional to the acceleration. The acceleration will be proportional to the net force, i.e., the vector sum of the two forces acting on each chest.

B3-RT11: ARROWS—ACCELERATION

All of the arrows were shot straight up into the air from the same height, and all are the same size and shape. The arrows are made of different materials so they have different masses. The masses of the arrows and their speeds as they leave the bows are given.



Rank the magnitude of the acceleration of the arrows at the top of their flight.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

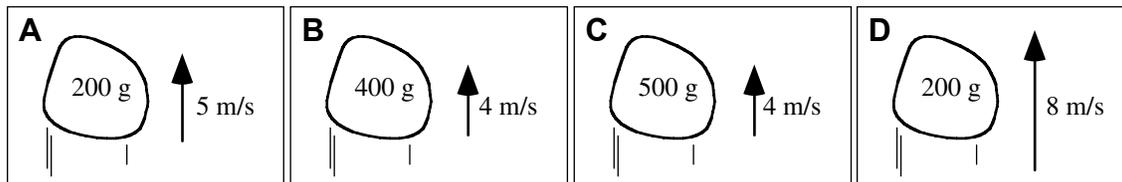
Explain your reasoning.

Answer: All the same.

The only force acting on these arrows is the gravitational force the Earth exerts on them, so they all have the same acceleration of 9.8 m/s^2 throughout their motion.

B3-RT12: ROCKS THROWN UPWARD—NET FORCE

Rocks that are thrown up into the air all have the same shape, but they have different masses. The masses of the rocks and their speeds when they were thrown are given.



Rank the magnitude of the net force on the rocks just after they are thrown.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

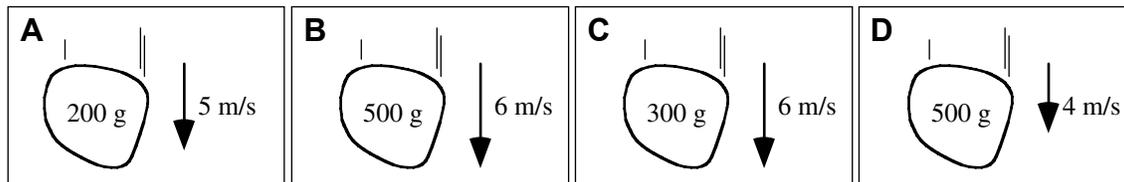
Explain your reasoning.

Answer: $C > B > A = D$.

The net force acting on each rock is the gravitational force the Earth exerts on the rock (the weight of the rock). The gravitational force is proportional to the mass of the rock, so the ranking depends on the masses of the rocks only.

B3-RT13: ROCKS THROWN DOWNWARD—NET FORCE

Rocks that are thrown straight downward all have the same shape, but they have different masses. The masses of the rocks and their speeds when they were thrown are given.



Rank the magnitude of the net force on the rocks just after they are thrown.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

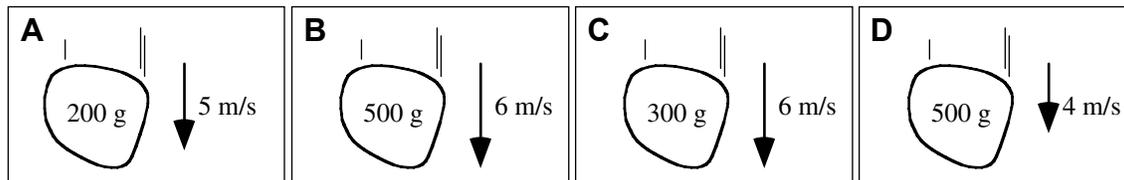
Explain your reasoning.

Answer: B = D > C > A.

The net force acting on each rock is the gravitational force the Earth exerts on the rock (the weight of the rock). The gravitational force is proportional to the mass of the rock, so the ranking depends on the masses of the rocks only.

B3-RT14: ROCKS THROWN DOWNWARD—ACCELERATION

Rocks that are thrown straight downward all have the same shape, but they have different masses. The masses of the rocks and their speeds when they were thrown are given.



Rank the magnitude of the acceleration of the rocks just after they are thrown.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

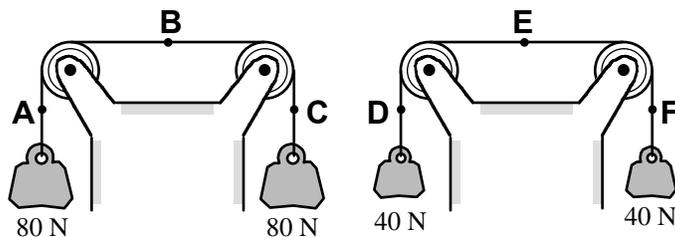
Explain your reasoning.

Answer: All the same.

The net force acting on each rock is the gravitational force the Earth exerts on the rock (the weight of the rock). The gravitational force is proportional to the mass of the rock, so when we divide the net force by the mass to get the acceleration the masses of the rocks cancel, and they all have the same acceleration of 9.8 m/s^2 .

B3-RT15: BLOCKS ATTACHED TO FIXED OBJECTS—ROPE TENSION

Two weights are attached by a rope and suspended from pulleys. The weights differ in the two cases, but the systems are at rest in both cases.



Rank the tension in the ropes at the points indicated.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>					
1	2	3	4	5	6		All	All	Cannot
Greatest					Least		the same	zero	determine

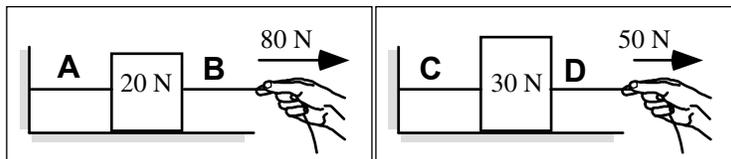
Explain your reasoning.

Answer: $B = A = C > E = D = F$.

Since the systems are at rest the vector sum of the forces on each block is zero, so the tension in the rope must equal the weight of the block.

B3-RT16: BLOCKS ATTACHED TO WALL—ROPE TENSION

Two blocks are attached by a rope to a wall. A child pulls horizontally on a second rope attached to each block. Both blocks remain at rest on the frictionless surface. The weights of the blocks and the magnitudes of the forces exerted by the child are given.



Rank the tensions in the ropes.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

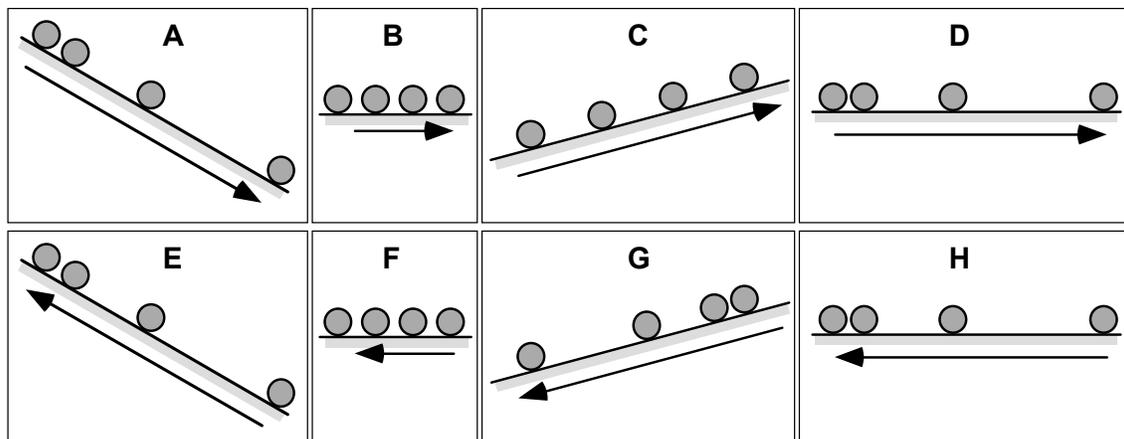
Explain your reasoning.

Answer: $B = A > D = C$.

Since the blocks remain at rest, the vector sum of the forces on the blocks in the horizontal direction must be zero. So the tensions in the two ropes in the left case are both 80 N and the tensions in the right case are both 50 N.

B3-QRT19: BALL STROBE MOTION—NET FORCE

The following drawings indicate the positions, using a strobe flash, of a ball moving from one side of the figure to the other as indicated by the direction of the arrow. Each circle represents the position of the ball at succeeding instants of time. Each time interval between successive positions is equal, and each ball has the same mass. Assume the acceleration, if any, for each situation to be constant.



(a) In which of these cases, if any, is there a net force acting on the ball? _____

Explain your reasoning.

Answer: A, D, E, G, H or all except B, C and F.

If the ball is accelerating, then the distance the ball travels in each time interval will change in a systematic way over time. If the balls are accelerating, there is a net force on them.

(b) In which of these cases, if any, is there a component of the net force directed to the right? _____

Explain your reasoning.

Answer: A, D, E, H.

To have a net force directed to the right there needs to be an acceleration directed to the right. Such an acceleration will produce either an increasing speed to the right—A and D—or a decreasing speed to the left—E and H.

(c) In which of these cases, if any, is there a component of the net force on the ball directed upward? _____

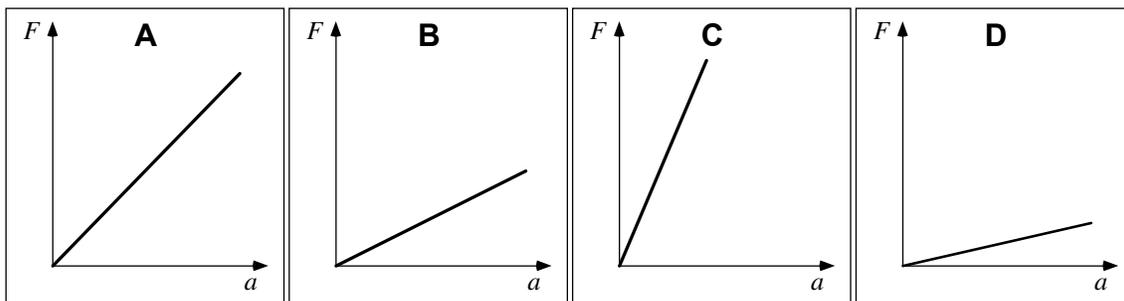
Explain your reasoning.

Answer: None.

To have an upward directed component the ball would have to be accelerating up the incline, none of these balls are doing that.

B3-RT20: NET FORCE-ACCELERATION GRAPHS—MASS

These graphs are of net force versus acceleration for different objects. All graphs have the same scale for each respective axis.



Rank the mass of the objects.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

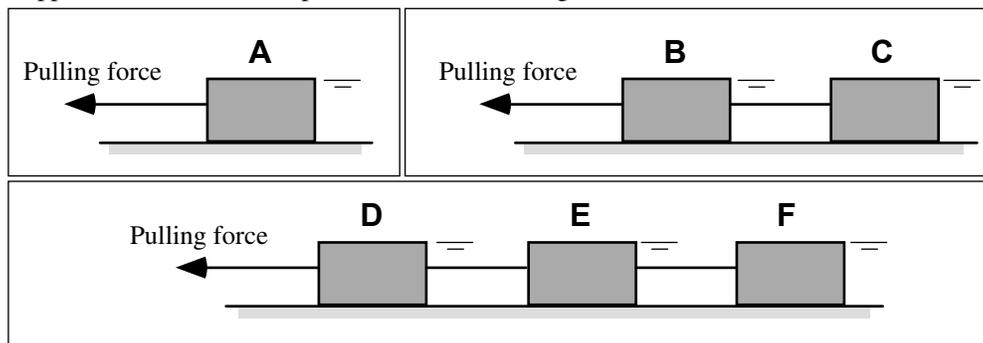
Explain your reasoning.

Answer: $C > A > B > D$.

The slopes of these graphs—given by the force divided by the acceleration—is the mass of the object involved.

B3-RT21: ROPES PULLING BOXES—ACCELERATION

Boxes are pulled by ropes along frictionless surfaces, accelerating toward the left. All of the boxes are identical. The pulling force applied to the left-most rope is the same in each figure.



Rank the accelerations of the blocks.

1	2	3	4	5	6	OR	All the same	All zero	Cannot determine		
Greatest						Least					

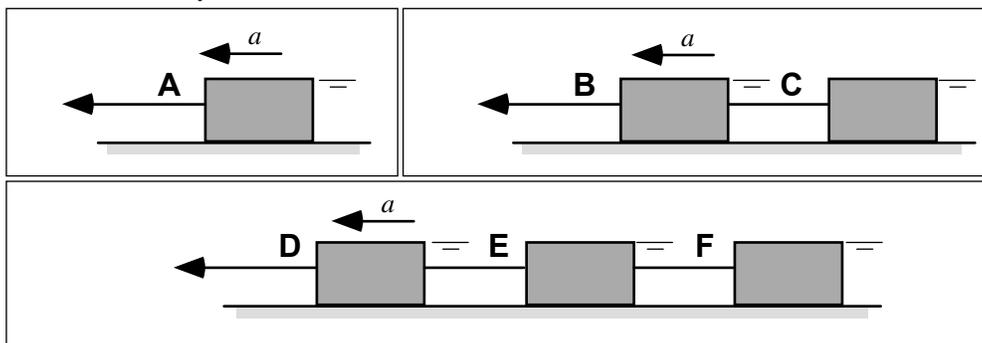
Explain your reasoning.

Answer: $A > B = C > D = E = F$.

Since the same net force is acting on all three systems the accelerations will depend on the masses of the systems and all masses in a system will have the same acceleration.

B3-RT22: ROPES PULLING BOXES—ROPE TENSION

Boxes are pulled by ropes along frictionless surfaces, accelerating toward the left. All of the boxes are identical, and the accelerations of all three systems are the same.



Rank the tensions in the ropes.

						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest						Least			

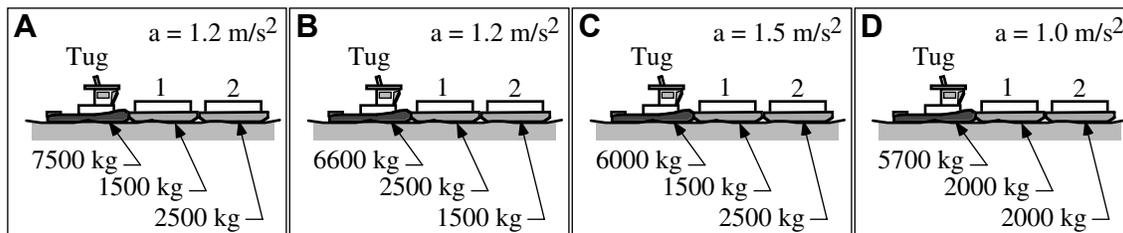
Explain your reasoning.

Answer: $D > B = E > A = C = F$.

Since the boxes all have the same mass (m) and all of the accelerations are the same, the tensions will be determined by how many boxes the rope is accelerating. The only horizontal force on the rightmost blocks in each case is the tension in the rope to the left of that block (A, C, and F), and this tension must therefore be the mass of that block times the acceleration, ma . The tension in ropes B and E are the net forces on the systems of the two blocks to their right, so the tensions in these ropes must be $2ma$. For the system of all 3 blocks in the last case the net force is the tension in rope D, $3ma$.

B3-RT23: TUGBOAT PUSHING BARGES—FORCE TUGBOAT EXERTS ON LEAD BARGE

A tugboat is pushing two barges (labeled 1 and 2) so that they speed up. The masses of the tugboats and barges and the accelerations of the systems are given for each case. Ignore the effects of fluid friction.



Rank the magnitude of the force the tugboat exerts on barge two.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

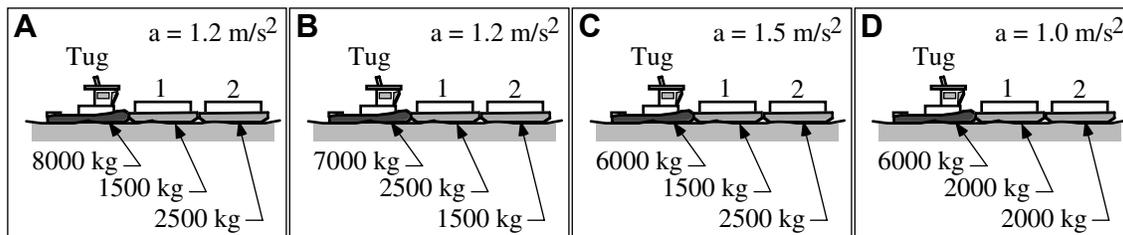
Explain your reasoning.

Answer: The force the tugboat exerts on barge two is zero for all cases.

Since the tugboat is not in contact with the lead barge it does not exert a force on it. (We are ignoring the miniscule gravitational force between the two.)

B3-RT24: TUGBOAT PUSHING BARGES—FORCE TUGBOAT EXERTS ON FIRST BARGE

A tugboat is pushing two barges (labeled 1 and 2) so that they speed up. The masses of the tugboats and barges and the accelerations of the systems are given for each case. Ignore the effects of fluid friction.



Rank the magnitude of the force the tugboat exerts on barge one.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

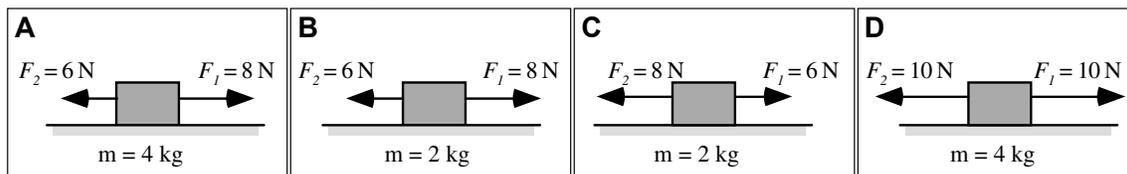
Explain your reasoning.

Answer: $C > A = B > D$.

The total mass of the two barges is the same for all six systems, so the net force on the two barges is proportional to the acceleration. Since we are ignoring fluid friction, the force the tugboat exerts on barge one is the only horizontal force on the system of the two barges, and this force is therefore equal to the mass of the two barges times the acceleration. The ranking of the force the tugboat exerts on barge one is the same as the ranking of the accelerations.

B3-RT25: FORCES ON BLOCKS ON SMOOTH SURFACES—SPEED

Two forces act on a block that is initially at rest on a frictionless surface.



Rank the speed of the block after 3 seconds.

<input style="width: 100%; height: 20px;" type="text"/>	OR	<input style="width: 100%; height: 20px;" type="text"/>	<input style="width: 100%; height: 20px;" type="text"/>	<input style="width: 100%; height: 20px;" type="text"/>			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

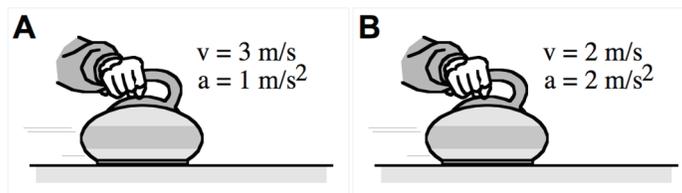
Explain your reasoning.

Answer: $B = C > A > D$.

The change in speed will be determined by the acceleration, which is the net force divided by the mass of the object. The net force in each case is the vector sum of the forces.

B3-CT26: CURLER PUSHING STONE—FORCE ON STONE

Two identical curling stones (the playing pieces in the sport of curling) are pushed horizontally on ice by curlers. The instantaneous speed and acceleration of the two stones are given. Ignore the friction between the stone and the ice.



Is the magnitude of the force that the curler is exerting on the stone (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

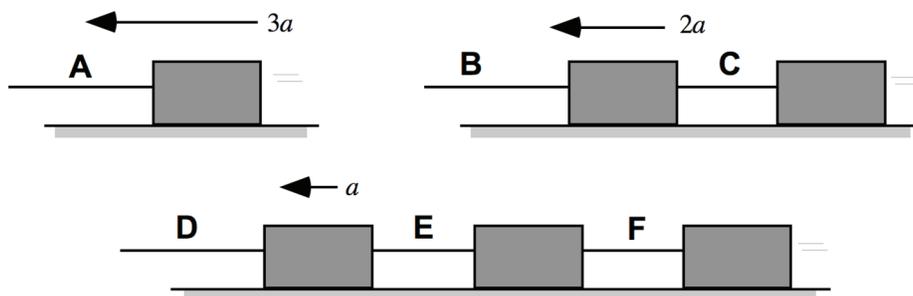
Explain your reasoning.

Answer: The force in Case A is less than force in Case B.

The stones have the same mass and there is a larger acceleration in B. Ignoring friction from the ice during this time (it is small compared to the horizontal force the thrower exerts on the stone) we can use $F_{\text{by the curler}} = m_{\text{stone}} a$.

B3-RT27: ROPES PULLING IDENTICAL BOXES—ROPE TENSION

Boxes are pulled by ropes along frictionless surfaces, accelerating toward the left. All of the boxes are identical, and the accelerations of the boxes are indicated.



Rank the tension in these ropes.

1	2	3	4	5	6	OR	All the same	All zero	Cannot determine		
Greatest						Least					

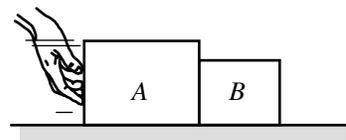
Explain your reasoning.

Answer: $B > D = A > C = E > F$.

Since the surface is frictionless, the tension in all ropes is the net force on the system of all blocks to the right of that rope. So the tension is equal to the mass of all blocks to the right of that rope times the acceleration. For rope A, this is $(m)(3a)$; for B it is $(2m)(2a)$; for C it is $(m)(2a)$; for D it is $(3m)(a)$; for E it is $(2m)(a)$; and for F it is $(m)(a)$.

B3-QRT28: STUDENT PUSHING TWO BLOCKS—FORCE

A student pushes horizontally on two blocks, which are moving to the right. Block A has more mass than block B. There is friction between the blocks and the table.



(a) For the situation where the blocks are moving at a constant speed, which of the following statements is true about the magnitude of the forces?

- (i) The force that block A exerts on block B is *greater than* the force that block B exerts on block A.
- (ii) The force that block A exerts on block B is *less than* the force that block B exerts on block A.
- (iii) The force that block A exerts on block B is *equal to* the force that block B exerts on block A.
- (iv) We cannot compare the forces unless we know how fast the blocks are slowing down.

Explain your reasoning.

Answer iii. These two forces are a Newton's Third Law pair.

(b) For the situation where the blocks are moving at a constant speed, which of the following statements is true about the net force?

- (i) The net force on block A points *to the right* and is *equal to* the net force on block B.
- (ii) The net force on block A points *to the left* and is *equal to* the net force on block B.
- (iii) The net force on block A points *to the right* and is *greater than* the net force on block B.
- (iv) The net force on block A points *to the left* and is *greater than* the net force on block B.
- (v) The net force on block A points *to the right* and is *less than* the net force on block B.
- (vi) The net force on block A points *to the left* and is *less than* the net force on block B.
- (vii) None of these are correct.

Explain your reasoning.

Answer vii. The blocks are moving at a constant speed and so the net force on each block must be zero.

(c) For the situation where the blocks are slowing down, which of the following statements is true about the magnitude of the forces?

- (i) The force that block A exerts on block B is *greater than* the force that block B exerts on block A.
- (ii) The force that block A exerts on block B is *less than* the force that block B exerts on block A.
- (iii) The force that block A exerts on block B is *equal to* the force that block B exerts on block A.
- (iv) We cannot compare the forces unless we know how fast the blocks are slowing down.

Explain your reasoning.

Answer iii. The force on B by A and the force on A by B form a Newton's Third Law pair, and are equal and opposite regardless of the state of motion of the blocks.

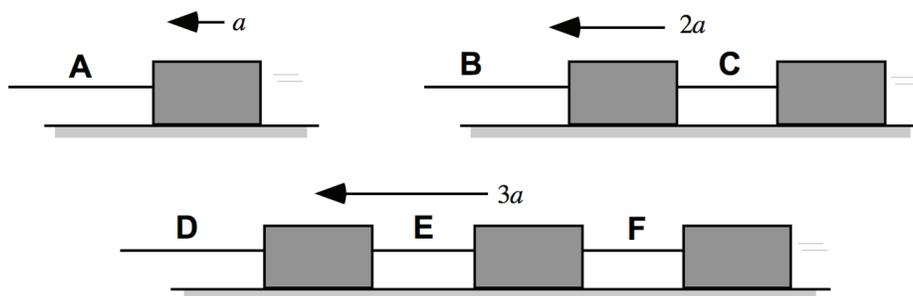
(d) For the situation where the blocks are slowing down, which of the following statements is true about the net force?

- (i) The net force on block A points *to the right* and is *equal to* the net force on block B.
- (ii) The net force on block A points *to the left* and is *equal to* the net force on block B.
- (iii) The net force on block A points *to the right* and is *greater than* the net force on block B.
- (iv) The net force on block A points *to the left* and is *greater than* the net force on block B.
- (v) The net force on block A points *to the right* and is *less than* the net force on block B.
- (vi) The net force on block A points *to the left* and is *less than* the net force on block B.
- (vii) None of these are correct.

Answer iv. The blocks are accelerating to the left since they are slowing down, and A has the larger mass.

B3-RT29: ROPES PULLING IDENTICAL BOXES—ROPE TENSION

Boxes are pulled by ropes along frictionless surfaces, accelerating toward the left. All of the boxes are identical, and the accelerations of the boxes are indicated.



Rank the tension in these ropes.

						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest						Least			

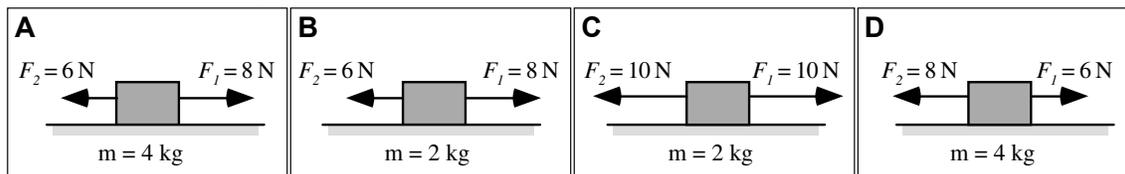
Explain your reasoning.

Answer: $D > E > B > F > C > A$.

Since the surface is frictionless, the tension in all ropes is the net force on the system of all blocks to the right of that rope. So the tension is equal to the mass of all blocks to the right of that rope times the acceleration. For rope A, this is $(m)(a)$; for B it is $(2m)(2a)$; for C it is $(m)(2a)$; for D it is $(3m)(3a)$; for E it is $(2m)(3a)$; and for F it is $(m)(3a)$.

B3-RT30: FORCES ON OBJECTS ON ROUGH SURFACES—VELOCITY CHANGE

Two forces act on identical objects that are on rough surfaces. The forces of maximum static and kinetic friction for all cases are both 1 N. All objects start at rest.



Rank the magnitude of the velocity change of the blocks in a 2-second time interval.

<input style="width: 90%; height: 90%;" type="text"/>	OR	<input style="width: 90%; height: 90%;" type="text"/>	<input style="width: 90%; height: 90%;" type="text"/>	<input style="width: 90%; height: 90%;" type="text"/>			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: B > A = D > C.

The change in velocity will be determined by the acceleration, which is the net force divided by the mass of the object. The net force in each case is the vector sum of the forces. Since we are only interested in the magnitudes of the changes the difference in direction for A and D does not matter.

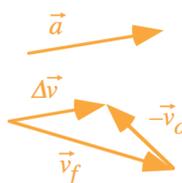
B3-QRT31: SKATEBOARD RIDER COASTING DOWN A HILL—ACCELERATION AND NET FORCE

At the instant shown, a skateboard rider is coasting down a hill and speeding up. Consider the skateboard and the rider as a single system and ignore friction.



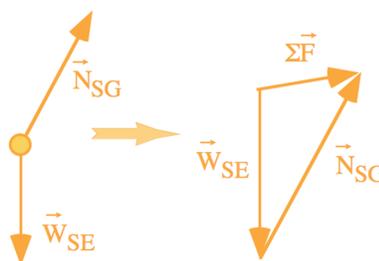
(a) Use velocity vectors to find the approximate direction of the acceleration of the system.

Answer: Since the rider is speeding up, we need to draw a final velocity vector that is longer than the initial velocity vector. From the difference $v_f - v_i$ shown, we can see that the change in velocity vector (and therefore the acceleration vector) points up and to the right as shown. Note that we can think of this acceleration as having two components: A tangential acceleration that is parallel to the surface in the direction of motion (because the skater is speeding up) and a radial acceleration pointing toward the center of curvature (because the skater is changing direction).



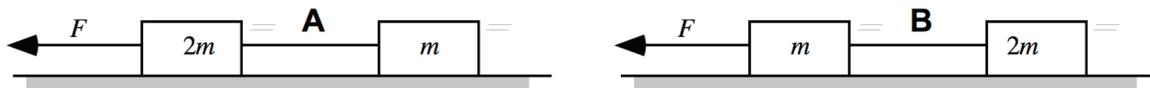
(b) Draw a free-body diagram for the system labeling all forces, and explain how the forces in your free-body diagram add to give a net force in the direction of the acceleration.

Answer: The only forces acting on the skater are a normal force and a weight. Using S to denote the skateboarder system, G for the surface of the ground, and E for the earth, we can draw. When we construct the vector sum diagram, we adjust the lengths of these vectors (without changing their directions!) so that the resultant points in the same direction as the change in velocity vector (which is in the same direction as the acceleration. Newton's second law is a vector equation, so we have to make sure that the direction of the net force is the same as the direction of the acceleration.



B3-CT32: ROPES PULLING BOXES—ROPE TENSION

Two boxes are pulled by the same force F along frictionless surfaces, accelerating toward the left. The masses of the boxes are indicated in each figure.



Will the tension in rope A on the left be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the tension in rope B on the right? _____

Explain your reasoning.

Answer: The tension in rope A is less than the tension in rope B.

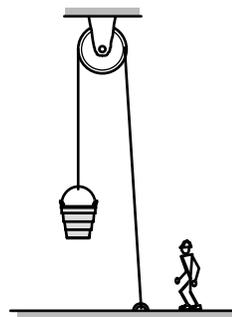
Since the surface is frictionless, the tension in all ropes is the net force on the system of all blocks to the right of that rope. So the tension is equal to the mass of all blocks to the right of that rope times the acceleration. Since the tension in the leftmost rope is F and the mass of the two blocks is $3m$ in each case, the acceleration of both systems is the same. For rope A, the tension is the acceleration times m . For rope B the tension is the (same) acceleration times $2m$, twice the tension of rope A.

B3-WWT33: LIFTING UP A PAIL—STRATEGY

A loaded pail is attached to a rope that passes around an overhead pulley and is tied to a ring on the floor. Linda, a construction worker, plans to untie the rope from the ring, pull on the rope to lift the pail 1 m higher, and then retie the rope. Linda weighs 800 N and is capable of lifting twice her weight, 1600 N. The loaded pail weighs 1200 N.

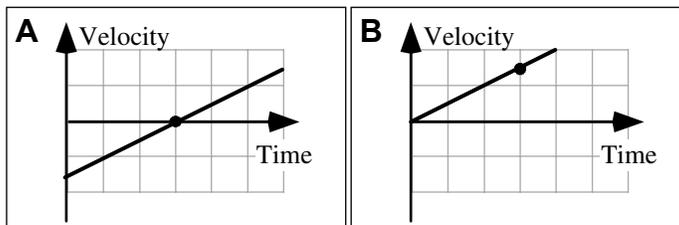
What, if anything, is wrong with Linda's plan? Explain how to correct it, or if the plan will work, explain why.

Answer: Linda can only exert a downward force equal to her weight of 800 N or less, so she cannot do it. The tension in the rope is equal to the weight of the pail, 1200 N. When she unties the rope, the tension in the rope will be acting upward on her and her weight will be acting down. The net force acting on her will be upward, and she will be accelerated upward, off the ground.



B3-WWT34: VELOCITY-TIME GRAPHS—NET FORCE

Graphs are shown of the velocity versus time for two identical train engines on a straight track. A positive velocity indicates that the engine was traveling east. The scales on both axes are the same for the graphs. On each graph a point is marked with a dot.



A student comparing the net force acting on the engine at the identified points in graphs A and B states:

“I think that B has the larger net force since the net force on A at the identified point is zero.”

What, if anything, is wrong with this statement? If something is wrong, identify it, and explain how to correct it. If the statement is correct, explain why.

Answer: The student's contention is wrong.

Since both graphs have the same slope both engines have the same acceleration. Since they are identical they also have the same mass and therefore the same net force for the intervals shown.

B3-CT35: BLOCKS MOVING AT CONSTANT SPEED—FORCE ON BLOCK

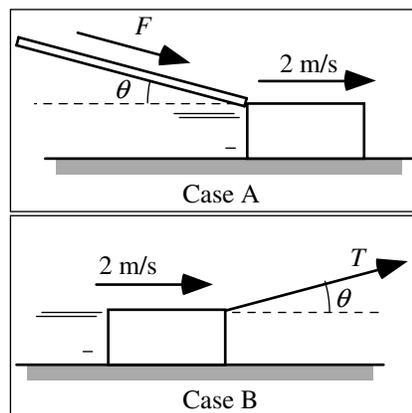
A block is moving to the right across a rough table at a constant speed of 2 m/s. The tables and the blocks are identical in the two cases. In Case A, the block is pushed with a stick and in Case B, the block is pulled with a string. The angle that the applied force makes with the horizontal is the same in both cases.

Will the magnitude of the force on the block by the stick in Case A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the tension on the block by the string in Case B? _____

Explain your reasoning.

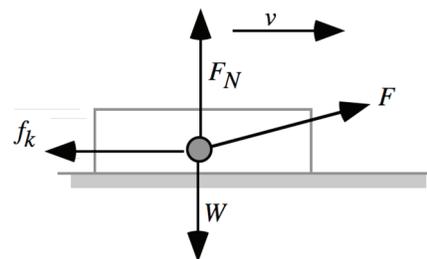
Answer: Greater in case A.

The force of the stick on the block has a downward component in case A, and for the net force in the vertical direction to be zero the normal force must be greater than the weight. In case B, the tension in the string has an upward vertical component, and since the net vertical force is again zero, the normal force must be less than the weight. Since the weight of both blocks is the same, the normal force on the block in Case A must be greater than the normal force on the block in case B. Since the normal force in Case A is greater, the friction force on the block by the table is greater in Case A than in case B. And since the net horizontal force is zero in both cases, the force on the block by the stick in Case A must be greater than the tension on the block by the string in case B.



B3-WWT36: PULLING A BLOCK ACROSS A ROUGH SURFACE—FORCE RELATIONSHIPS

A person pulls a block across a rough horizontal surface at a constant speed by applying a force F at a slight angle as shown. A free-body diagram is drawn for the block. The arrows in the diagram correctly indicate the directions but not necessarily the magnitudes of the various forces on the block. A student makes the following claim about this free-body diagram:



“The velocity of the block is constant, so the net force acting on the block must be zero. Thus the normal force F_N equals the weight W , and the force of friction f_k equals the applied force F .”

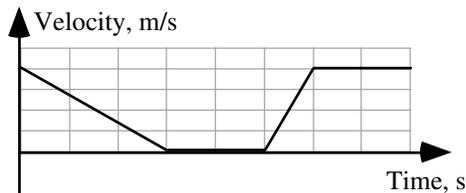
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The statement is wrong.

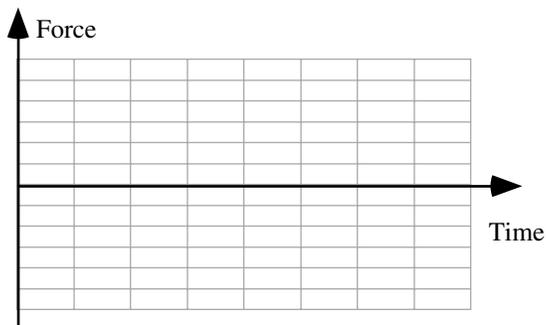
The block is not accelerating, so the student is right that there is no net force, that means the sum of the vertical forces is therefore zero and the sum of the horizontal forces is also zero. Thus the horizontal component of F must be equal to the frictional force ($F \cos \theta = f_k$), and the weight must equal the normal force plus the vertical component of the applied force F ($W = F_N + F \sin \theta$).

B3-CRT37: VELOCITY-TIME GRAPH—FORCE-TIME GRAPH

Shown is the velocity versus time graph for an object that is moving in one dimension under the (perhaps intermittent) action of a single horizontal force.

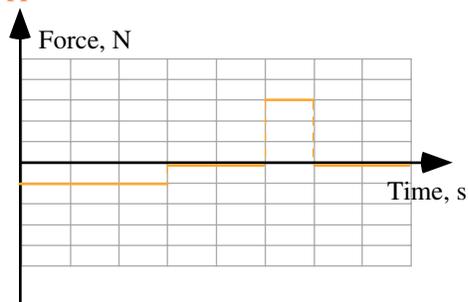


On the axes below, draw the horizontal force acting on this object as a function of time.



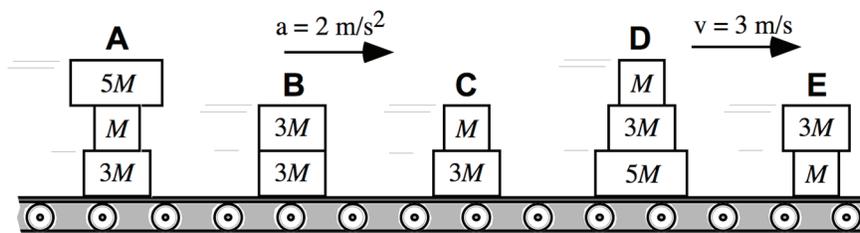
Explain your reasoning.

Answer: When the velocity is constant (the velocity/time graph is horizontal) there is no acceleration and therefore no force. When the slope of the velocity/time graph is steep, there is a large acceleration and therefore a large net force. Since there is only one force acting on the object, this force is the net force. The force is in the same direction as the velocity when the acceleration (the slope of the velocity-time graph) is positive, and in the opposite direction when the acceleration is negative.



B3-RT38: STACKED BLOCKS SPEEDING UP ON A CONVEYOR BELT—NET FORCE

Various stacks of blocks are traveling along a conveyor belt. At the instant shown, all blocks have the same velocity of 3 m/s to the right and the same acceleration of 2 m/s², also to the right. The blocks do not slip. All masses are given in the diagram in terms of M , the mass of the smallest block.



Rank the magnitude of the net force on each stack of blocks.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>				
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

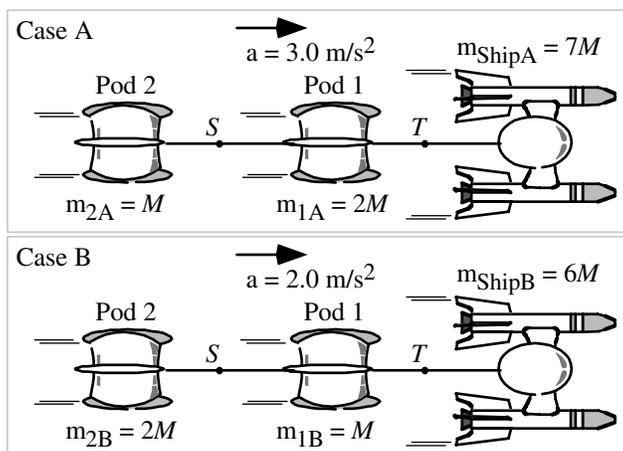
Explain your reasoning.

Answer $A = D > B > C = E$.

The net force for each stack is equal to the mass of that stack times its acceleration. Since all stacks have the same acceleration, the net force is proportional to the mass of each stack. Stacks A and D have a total mass of $9M$, C and E have a mass of $4M$, and B has a mass of $6M$. The net force is to the right, in the same direction as the acceleration.

B3-CT39: SPACESHIPS PULLING TWO CARGO PODS—TENSION IN TOW RODS

In both cases a spaceship is pulling two cargo pods, one empty and one full. At the instant shown, the speed of the pods and spaceships is 300 m/s, but they have different accelerations as shown. All masses are given in terms of M , the mass of an empty pod.



(a) Will the tension at point S in the tow rod be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

Answer: Greater in case B.

In both cases the net force on the second pod is equal to the tension in the tow rod, and this will equal the mass of the second pod times the acceleration of that pod. The net force on Pod 2 is therefore the mass of Pod 2 times the acceleration. For Case A it is $M(3 \text{ m/s}^2)$ and for B it is $2M(2 \text{ m/s}^2)$. So the tension at point S in Case B is four thirds the tension at point S in Case A.

(b) Will the tension at point T in the tow rod be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

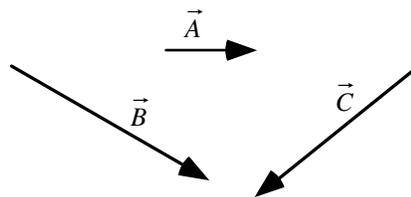
Answer: (a) Greater in case A.

In both cases the rod is pulling both pods with a combined mass of $3M$. The net force on a system consisting of Pod 1 and Pod 2 is just the tension in the rod between the ship and Pod 1. Since the masses are the same, and the acceleration is greater in case A, the net force (and the tension at point P) will be greater in case A.

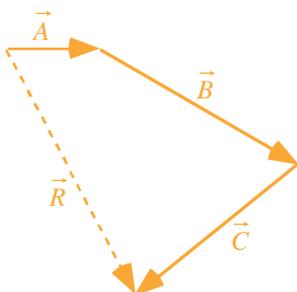
B3-QRT40: THREE VECTORS—RESULTANT

(a) In the space below, add the three vectors shown and label the resultant vector as \vec{R} . Be sure to clearly indicate the direction of the resultant.

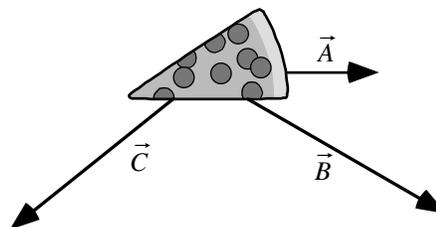
Explain your reasoning.



Answer:



Suppose the three vectors above represent forces exerted on a slice of pepperoni pizza by three people, Abel (\vec{A}), Beth (\vec{B}), and Celia (\vec{C}) as shown in the top view picture to the right. A fourth person, David, also pulls on the pizza. The pizza moves to the left at a constant speed. Assume there is no friction between the pizza slice and the greasy table.

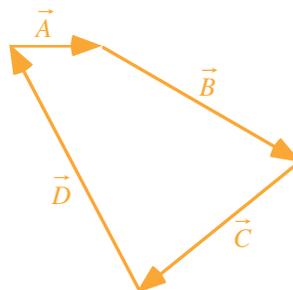


(b) In what direction is David pulling on the pizza?

Explain your reasoning.

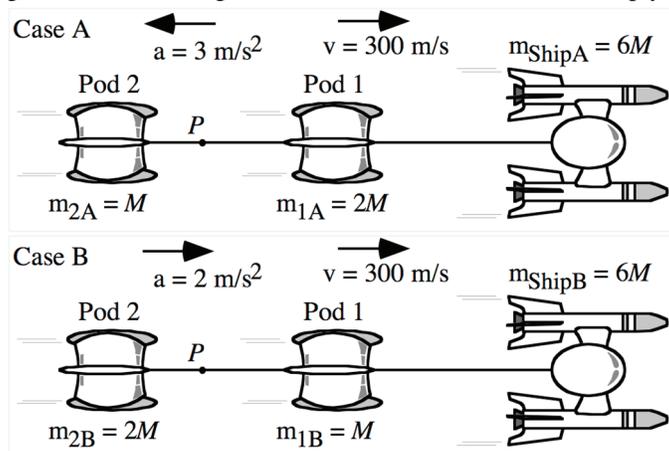
Answer:

David must be exerting a force up and to the left, in the opposite direction to the resultant found in part A. Since the pizza slice is moving at a constant speed, the net force on it must be zero. So the vector representing the force that David exerts on the pizza slice must add to the other three to give a zero net force.



B3-CT41: SPACESHIPS PULLING TWO CARGO PODS—TENSION OR COMPRESSION IN TOW RODS

In each case below, a spaceship is attached to two cargo pods by rods. At the instant shown, the speed of the pods and of the spaceship is 300 m/s. In Case A the acceleration of the ship and of the pods is 3 m/s^2 to the left, while in Case B it is 2 m/s^2 to the right. All masses are given in terms of M , the mass of an empty pod.



Will the tension or compression at point P in the tow rod be (i) greater in Case A, (ii) greater in Case B, or (iii) the same in both cases? _____

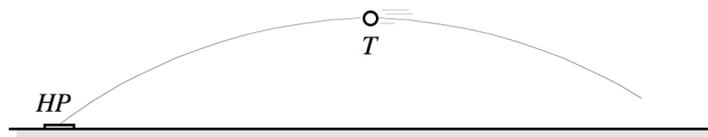
Explain your reasoning.

Answer: Greater in case B.

In both cases the net force on the second pod is equal to the tension (or compression) in the tow rod, and this will equal the mass of the second pod times the acceleration of that pod. The net force on Pod 2 is therefore the mass of Pod 2 times the acceleration. For Case A it is $M(2 \text{ m/s}^2)$ to the left, and for B it is $2M(2 \text{ m/s}^2)$ to the right. So the tension at point P in Case B is twice the magnitude of the compression at point P in Case A.

B3-QRT42: THROWN BASEBALL—FREE-BODY DIAGRAM AT THE TOP

A baseball is thrown from right field to home plate (HP), traveling from right to left in the diagram.



A group of physics students watching the game create the following free-body diagrams for the baseball at the top of its path (point *T*). Note that the forces are not drawn to scale.

<p>A</p>	<p>B</p>	<p>C</p>
<p>D</p>	<p>E</p>	<p>F</p>
<p>G</p> <p>None of these</p>	<p>H</p> <p>Depends on the coordinate system used</p>	

(a) If they decide to ignore air friction, which is the correct free-body diagram for the baseball at point *T*?

B, The only force acting is the weight of the ball since we are ignoring friction.

(b) Define all forces on the ball for this force diagram.

B is the gravitational force on the baseball by the earth (i.e., the weight of the baseball).

(c) If they decide to include air friction, which is the correct free-body diagram for the baseball at point *T*?

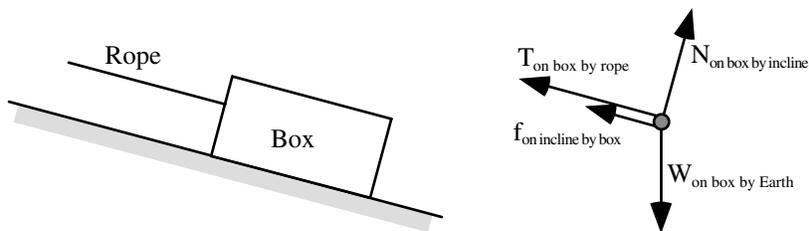
Diagram E includes air friction (A) acting opposite to the direction of motion, and the force of gravity (B).

(d) Define all forces on the ball for this force diagram.

B is the gravitational force on the baseball by the earth (i.e., the weight of the baseball) and A is the frictional force on the baseball by the air.

B3-WWT43: BOX ON INCLINE—FORCES

A heavy box is sitting at rest on an incline. There is friction between the box and the incline, and a rope is pulling on the box in a direction up and to the left, parallel to the incline. A physics student draws the free-body diagram below right for the box.

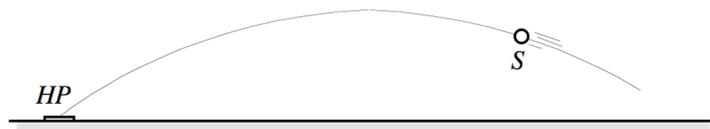


What, if anything, is wrong with this student's free-body diagram? If something is wrong, explain the error and how to correct it. If this free-body diagram is correct, explain why.

Answer: The force acting on the incline by the box does not belong in the free-body diagram of the box. Only forces acting on the box can be in this free-body diagram. There should be a vector representing the friction force on the box by the incline, and this force should be parallel to the surface, but we don't have enough information to tell whether it points up the incline or down the incline. (Also if the free-body diagram was supposed to be to scale, the sum of the forces as drawn is not zero as it should be since the box is at rest -- there is a net force up the incline.)

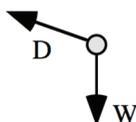
B3-WWT44: THROWN BASEBALL—FREE-BODY DIAGRAM FOR ASCENDING BASEBALL

A baseball is thrown from right field to home plate (HP), traveling from right to left in the diagram.



A physics student watching the game produces the free-body diagram shown below for the baseball as it moves upward at a point (S) along the path. She explains that in her drawing:

*“I’m ignoring air resistance. **W** is the weight of the baseball and **D** is the force of the throw on the baseball.”*



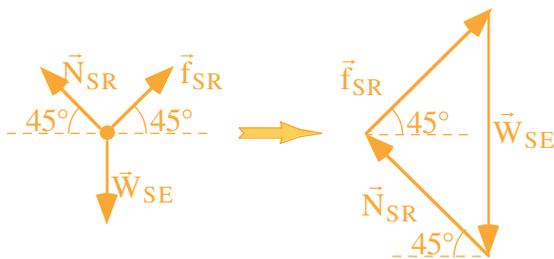
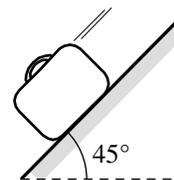
What, if anything, is wrong with this free-body diagram? If something is wrong, identify it and explain how to correct it. If this free-body diagram is correct, explain why.

*Answer- Force **D** does not exist since there is no longer any contact between ball and hand and therefore no interaction. **W** is correct and represents the gravitational force on the ball by the earth (the weight of the ball).*

B3-CRT45: SUITCASE SLIDING DOWN RAMP AT CONSTANT SPEED—FORCES ON SUITCASE

A suitcase is moving at a constant speed as it slides down a ramp angled at 45° to the horizontal.

Draw a free-body diagram below, labeling and defining all the forces on the suitcase.



Rank the magnitudes of these forces on the suitcase.

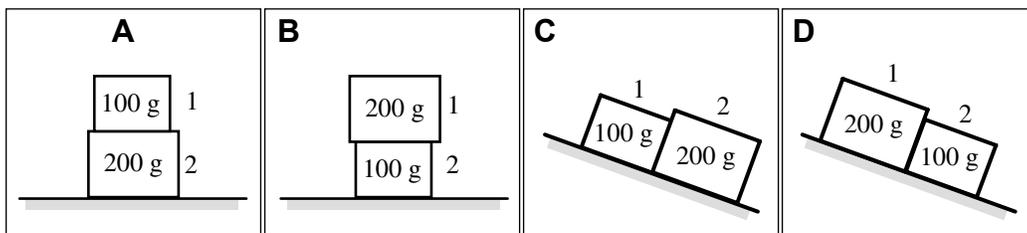
$$W_{SE} > N_{SR} = f_{SR}$$

Explain your ranking.

The suitcase is not changing speed or direction, so the net force on the suitcase must be zero. From the vector sum diagram, we see that the weight is the hypotenuse of a triangle, and so the weight is the largest force. Since the triangle is isosceles ($45^\circ, 45^\circ, 90^\circ$), the normal force and the friction have equal magnitude. (The coefficient of friction in this case must be 1, since the coefficient of friction is the ratio of the friction force to the normal force.) Note that N_{SR} means normal force exerted by the surface on the suitcase, W_{SE} indicates the gravitational force exerted by the earth on the suitcase, and f_{SR} is the friction force by the ramp on the suitcase.

B3-RT46: TWO BLOCKS AT REST—FORCE DIFFERENCE

In each case shown, there are two blocks with different masses that are at rest and in contact with each other. One of the blocks given in each arrangement is labeled **1**, and the other is labeled **2**. The mass of each block is given in the figures.



Rank the difference between the strengths (magnitudes) of the force 1 exerts on 2 and the force 2 exerts on 1.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

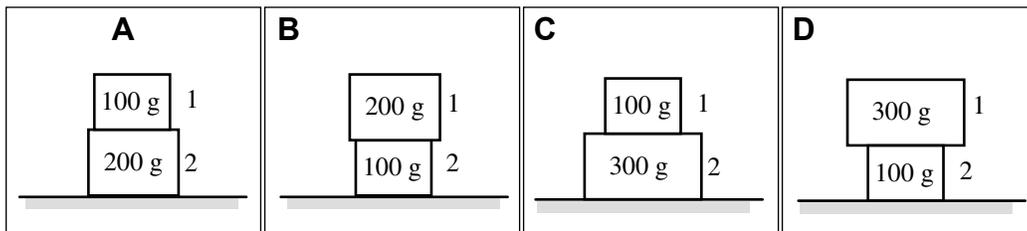
Explain your reasoning.

Answer: All differences are zero.

This question is asking about the difference in magnitude of two forces that form a Newton's third law pair. Since the pair of forces in Newton's third law always have the same magnitude this will always be zero.

B3-RT47: TWO STACKED BLOCKS AT REST—FORCE ON THE TOP BLOCK BY BOTTOM BLOCK

Two wooden blocks with different masses are at rest, stacked on a table. The top block is labeled **1**, and the bottom block is labeled **2**.



Rank the magnitude of the force that the bottom block (2) exerts on the top block (1).

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

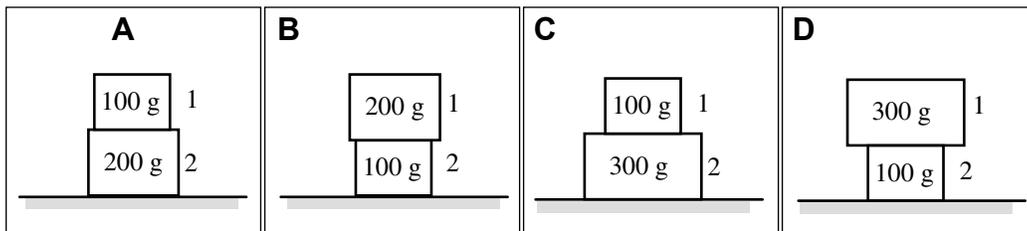
Explain your reasoning.

Answer: $D > B > A = C$.

The systems are at rest so the vector sum of the forces in the vertical direction has to be zero. There are two vertical forces acting on the top blocks, their weights, which are directed down, and the normal force that block 1 exerts, directed up. So the magnitudes of the forces that the lower blocks exert are equal to the weights of the top blocks.

B3-RT48: TWO STACKED BLOCKS AT REST—FORCE ON THE TOP BLOCK BY THE TABLE

Two wooden blocks with different masses are at rest, stacked on a table. The top block is labeled **1**, and the bottom block is labeled **2**.



Rank the magnitude of the force that the table exerts on the top block (1).

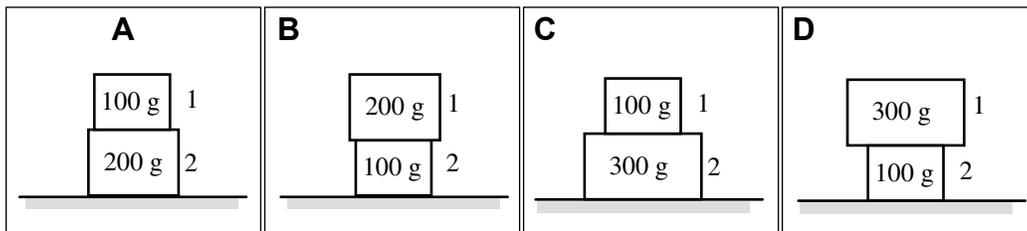
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: All zero since the top blocks are not in contact with the table.

B3-RT49: TWO STACKED BLOCKS AT REST—FORCE ON THE BOTTOM BLOCK BY TABLE

Two wooden blocks with different masses are at rest, stacked on a table. The top block is labeled **1**, and the bottom block is labeled **2**.



Rank the magnitude of the force that the table exerts on the bottom block (2).

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

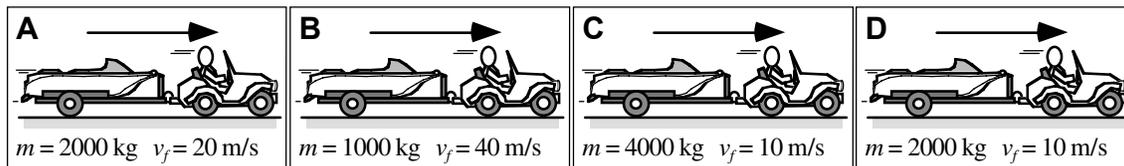
Explain your reasoning.

Answer: $C = D > A = B$.

The normal force the table exerts on the bottom block has to balance the other two forces—exerted by the Earth and the top block—on the bottom block.

B3-RT50: ACCELERATING CAR AND BOAT TRAILER—FORCE DIFFERENCE

All the trailers and cars shown are identical but the boat trailers have different loads. In each case, the car and boat trailer accelerate at 1 m/s^2 from rest to the final speed shown.



Rank the difference between the strength (magnitude) of the force the car exerts on the boat trailer and the strength of the force the trailer exerts on the car while the cars and trailers are accelerating.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

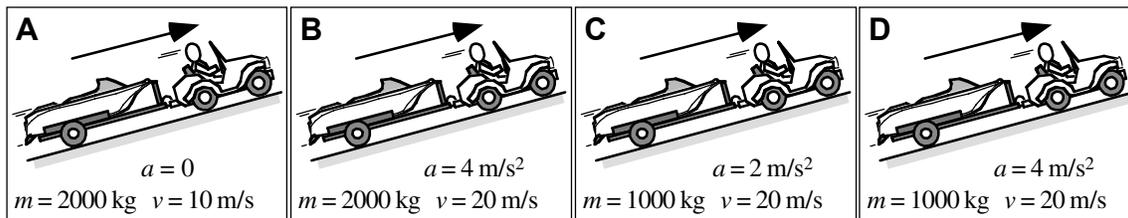
Explain your reasoning.

Answer: All the same—zero.

This question is asking about the difference between the magnitudes of Newton’s third law force pairs. Since the third law states that in all cases the force the car exerts on the trailer is equal in magnitude, but oppositely directed, to the force the trailer exerts on the car, the differences will all be zero.

B3-RT51: CAR AND BOAT TRAILER ON AN INCLINE—FORCE DIFFERENCE

All the trailers and cars shown are identical, but the boat trailers have different loads. The inclines are all identical. In each case, the accelerations and velocities are given for the instant shown.



Rank on the difference between the strength (magnitude) of the force the car exerts on the boat trailer and the strength of the force the boat trailer exerts on the car.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: All the same—zero.

This question is asking about the difference between the magnitudes of Newton’s third law force pairs. Since the third law states that in all cases the force the car exerts on the trailer is equal in magnitude, but oppositely directed, to the force the trailer exerts on the car, the differences will all be zero.

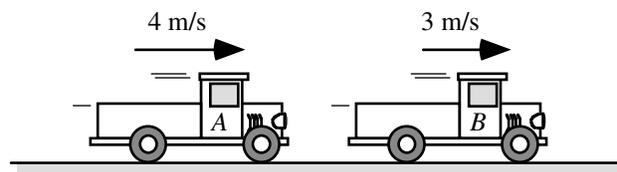
B3-CT52: IDENTICAL TOY TRUCK COLLISIONS—FORCE AND ACCELERATION

Two identical toy trucks traveling at different constant speeds are about to collide.

(a) The trucks are traveling in the same direction.

During the collision, will the magnitude of the force exerted on truck A by truck B be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the force exerted on truck B by truck A? _____

Explain your reasoning.

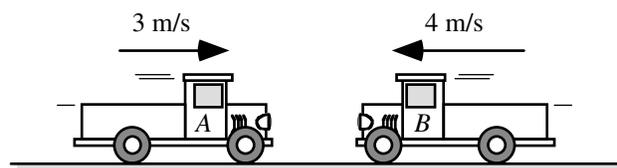


Answer: The magnitudes of the forces will be equal due to Newton's Third Law.

(b) The trucks are traveling in opposite directions.

During the collision, will the magnitude of the force exerted on truck A by truck B be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the force exerted on truck B by truck A? _____

Explain your reasoning.

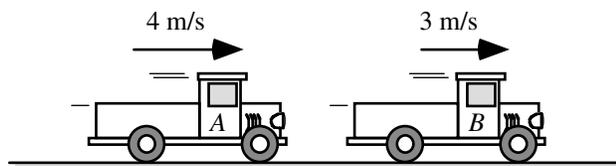


Answer: The magnitudes of the forces will be equal due to Newton's Third Law.

(c) The trucks are traveling in the same direction.

During the collision, will the magnitude of the acceleration of truck A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the acceleration of truck B? _____

Explain your reasoning.

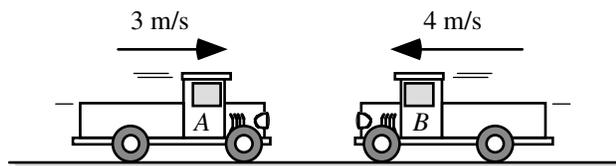


Answer: Equal magnitude accelerations since the magnitude of the forces will be equal due to Newton's Third Law and the masses of the two trucks are the same.

(d) The trucks are traveling in opposite directions.

During the collision, will the magnitude of the acceleration of truck A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the acceleration of truck B? _____

Explain your reasoning.



Answer: Equal magnitude accelerations since the magnitude of the forces will be equal due to Newton's Third Law and the masses of the two trucks are the same.

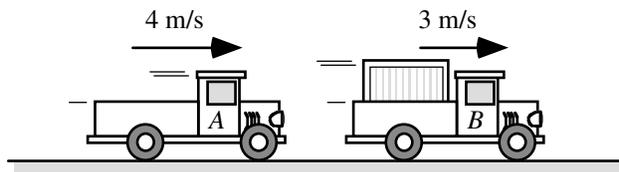
B3-CT53: TOY TRUCK COLLISIONS—FORCE ON TRUCKS

Two toy trucks traveling at different constant speeds are about to collide.

(a) The two identical trucks are traveling in the same direction, and truck B is carrying a heavy load.

During the collision, will the magnitude of the force exerted on truck A by truck B be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the force exerted on truck B by truck A? _____

Explain your reasoning.

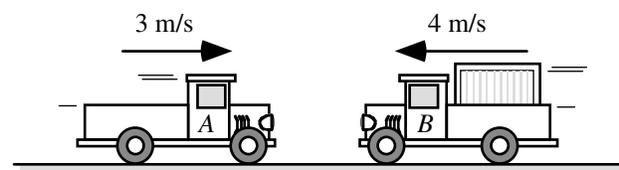


Answer: The forces will have the same magnitude due to Newton's Third Law.

(b) The two identical trucks are traveling in opposite directions, and truck B is carrying a heavy load.

During the collision, will the magnitude of the force exerted on truck A by truck B be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the force exerted on truck B by truck A? _____

Explain your reasoning.

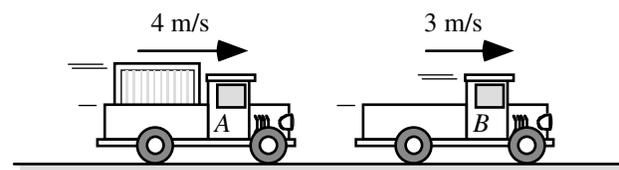


Answer: The forces will have the same magnitude due to Newton's Third Law.

(c) The two identical trucks are traveling in the same direction, and truck A is carrying a heavy load.

During the collision, will the magnitude of the force exerted on truck A by truck B be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the force exerted on truck B by truck A? _____

Explain your reasoning.

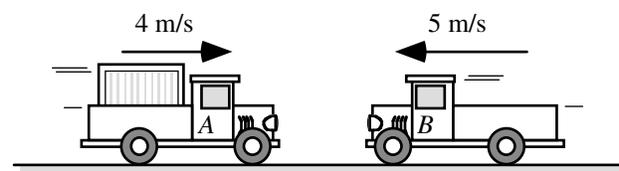


Answer: The forces will have the same magnitude due to Newton's Third Law.

(e) The two identical trucks are traveling in opposite directions, and truck A is carrying a heavy load.

During the collision, will the magnitude of the force exerted on truck A by truck B be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the force exerted on truck B by truck A? _____

Explain your reasoning.



Answer: The forces will have the same magnitude due to Newton's Third Law.

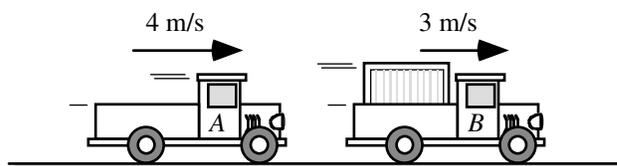
B3-CT54: TOY TRUCK COLLISIONS—ACCELERATION

Two toy trucks traveling at different constant speeds are about to collide.

(a) The two identical trucks are traveling in the same direction, and truck B is carrying a heavy load.

During the collision, will the magnitude of the acceleration of truck A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the acceleration of truck B? _____

Explain your reasoning.

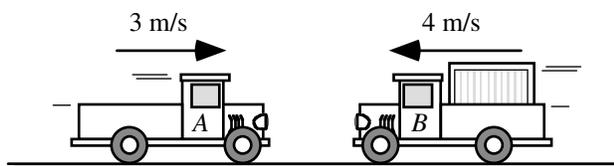


Answer: Greater than because the forces on A and B will have the same magnitude due to Newton's Third Law, and the mass of A is less, so the acceleration of A is larger using Newton's Second Law.

(b) The two identical trucks are traveling in opposite directions, and truck B is carrying a heavy load.

During the collision, will the magnitude of the acceleration of truck A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the acceleration of truck B? _____

Explain your reasoning.

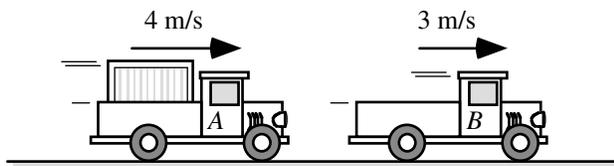


Answer: Greater than because the forces on A and B will have the same magnitude due to Newton's Third Law, and the mass of A is less, so the acceleration of A is larger using Newton's Second Law.

(c) The two identical trucks are traveling in the same direction, and truck A is carrying a heavy load.

During the collision, will the magnitude of the acceleration of truck A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the acceleration of truck B? _____

Explain your reasoning.



Answer: Less than because the forces on A and B will have the same magnitude due to Newton's Third Law, but the mass of A is greater, so the acceleration of A is smaller using Newton's Second Law.

B3-WWT55: TENNIS BALL AND RACQUET—FORCE

A tennis player returns a serve. A physics student watching the match makes the following contention:

“While the tennis ball is in contact with the tennis racquet, the racquet exerts a larger force on the tennis ball than the tennis ball does on the racquet because the racquet has to stop the tennis ball and then reverse its motion.”

What, if anything, is wrong with this contention? If something is wrong, explain the error and how to correct it. If this contention is correct, explain why.

Answer: This contention is wrong.

The racquet and ball exert equal magnitude forces on each other, as required by Newton’s Third Law.

B3-WWT56: BALL HITTING A WALL—FORCES

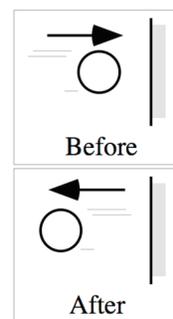
A student observes a rubber ball hitting a wall and rebounding. She states:

“In this situation, the wall exerts a larger force on the ball than the ball exerts on the wall, because the ball undergoes an acceleration but the wall doesn’t move. That is, the ball goes from an initial speed to zero and then from zero to the rebound speed, but the wall does not accelerate since it is stationary the whole time.”

What, if anything, is wrong with this contention? If something is wrong, identify it, and explain how to correct it. If this contention is correct, explain why.

Answer: The student is wrong.

The ball and wall exert equal magnitude, but oppositely directed, forces on each other as required by Newton’s Third Law.



B3-WWT57: POTATO ON TABLE—FORCES AND REACTION FORCES

A potato with a weight of 2 N is resting on a table. A student makes a number of statements about this situation.



- (a) “The weight of the potato is a force of 2 N exerted by Earth in the downward direction.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: This is correct, weight is the name of the force exerted by the earth in the downward direction.

- (b) “The reaction force to this weight is a force of 2 N exerted on the potato by the table in the upward direction.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: This is incorrect.

The “reaction” force is the other member of the Newton’s Third Law action-reaction pair, so for the force the earth exerts on the potato the reaction force is exerted on the earth by the potato in the upward direction.

- (c) “The normal force exerted on the potato by the table is a force of 2 N; the reaction force to this normal force is a force of 2 N exerted on the potato by Earth in the downward direction.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The reaction force to the normal force is exerted on the table by the potato in the downward direction.

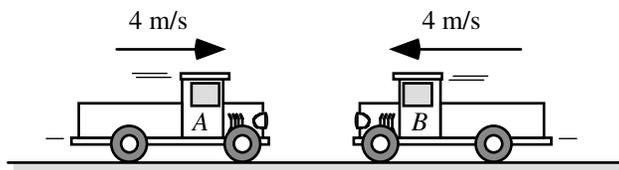
- (d) “If the 2 N potato is lifted off the table by a hand that exerts a force of 4 N upward on the potato, the reaction force to this 4 N force is a force of 4 N exerted on the hand by the potato in the downward direction.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer- This statement is correct, these are the correct forces in this Newton’s third law pair.

B3-LMCT58: IDENTICAL TOY TRUCKS COLLIDING HEAD-ON—FORCE ON TRUCKS

Two identical toy trucks traveling at the same speed in opposite directions are about to collide. The magnitude of the force exerted on truck A by truck B during the collision is equal to the magnitude of the force exerted on truck B by truck A.



Identify from choices (i)–(iv) how each change described below will affect the magnitude of the force exerted on truck A by truck B during the collision as compared to the magnitude of the force exerted on truck B by truck A.

This change will cause the magnitude of the force exerted on truck A by truck B to be:

- (i) *greater than* the magnitude of the force exerted on truck B by truck A.
- (ii) *less than* the magnitude of the force exerted on truck B by truck A.
- (iii) *the same* as the magnitude of the force exerted on truck B by truck A.
- (iv) *indeterminate as compared to* the magnitude of the force exerted on truck B by truck A.

All of these modifications are changes to the initial situation shown in the diagram.

(a) Truck A is carrying a heavy load. _____

Explain your reasoning.

For all items—a to f—the answer is iii.

The forces will have the same magnitude due to Newton's Third Law.

(b) Truck A is going faster than truck B. _____

Explain your reasoning.

The forces will have the same magnitude due to Newton's Third Law.

(c) Truck A is carrying a heavy load and is going faster than truck B. _____

Explain your reasoning.

The forces will have the same magnitude due to Newton's Third Law.

(d) Truck A is speeding up (accelerating). _____

Explain your reasoning.

The forces will have the same magnitude due to Newton's Third Law.

(e) Truck A is speeding up (accelerating) and is carrying a heavier load. _____

Explain your reasoning.

The forces will have the same magnitude due to Newton's Third Law.

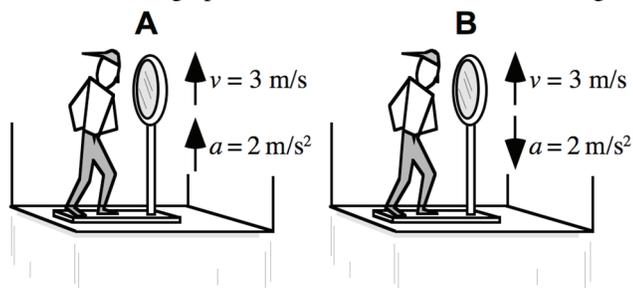
(f) Truck A is speeding up (accelerating) while truck B is carrying a heavier load. _____

Explain your reasoning.

The forces will have the same magnitude due to Newton's Third Law.

B3-CT59: PERSON IN AN ELEVATOR MOVING UPWARD—SCALE READING

A person who weighs 500 N is standing on a scale in an elevator. In both cases the elevator is identical and is moving upward, but in Case A it is accelerating upward and in Case B it is accelerating downward.



Will the scale reading be (i) *greater* in Case A, (ii) *greater* in case B, or (iii) *the same* in both cases? _____

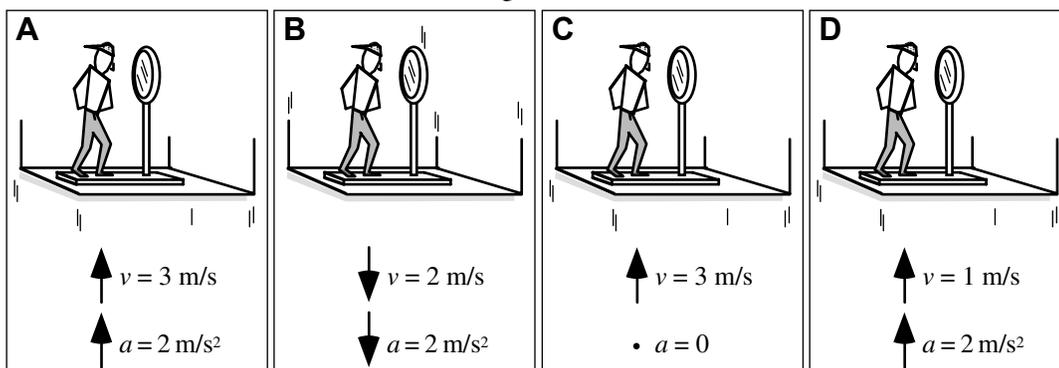
Explain your reasoning.

Answer: The scale reading will be greater in Case A.

By Newton's Second Law the net force on the person must point upward in Case A since the acceleration is upward and the net force will point downward in Case B since the acceleration is downward. So the normal force on the person by the scale (which is the reading on the scale) must be larger than the weight of the person in Case A, and smaller than the weight of the person in Case B. The direction of the velocity of the elevator is not relevant to the scale reading.

B3-RT60: PERSON IN A MOVING ELEVATOR—SCALE READING

A person who weighs 600 N is standing on a scale in an elevator. The elevator is identical in all cases. The velocity and acceleration of the elevators at the instant shown are given.



Rank the scale reading.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

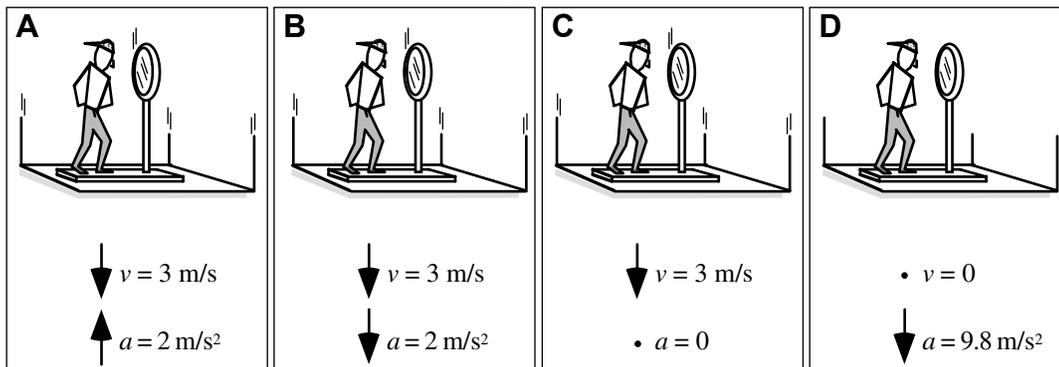
Explain your reasoning.

Answer: A = D > C > B.

The scale is providing the normal force on the person, and the scale reading indicates the magnitude of this force. For cases A and D that normal force is larger than the person's weight because the scale also has to accelerate the person upward. For case C the normal force is equal in magnitude to the person's weight, and for case B it is less than the person's weight since the person is accelerating downward.

B3-RT61: PERSON IN AN ELEVATOR MOVING DOWNWARD—SCALE READING

A person who weighs 600 N is standing on a scale in an elevator. The elevator is identical in all cases. The velocity and acceleration of the elevators at the instant shown are given.



Rank the scale reading.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

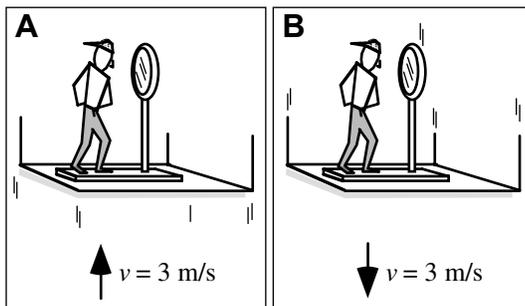
Explain your reasoning.

Answer: $A > C > B > D$.

The scale is providing the normal force on the person, and the scale reading indicates the magnitude of this force. For case A that normal force is larger than the person's weight because the scale also has to accelerate the person upward. For case C the normal force is equal, in magnitude, to the person's weight, for case B it is less than the person's weight since the person is accelerating downward, and in case D the scale reading will be zero since the person is in free fall.

B3-CT62: PERSON IN AN ELEVATOR—SCALE READING

A person who weighs 500 N is standing on a scale in an elevator. The elevator is identical in both cases. In both cases the elevator is moving at a constant speed, upward in Case A and downward in Case B.



Will the scale reading be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

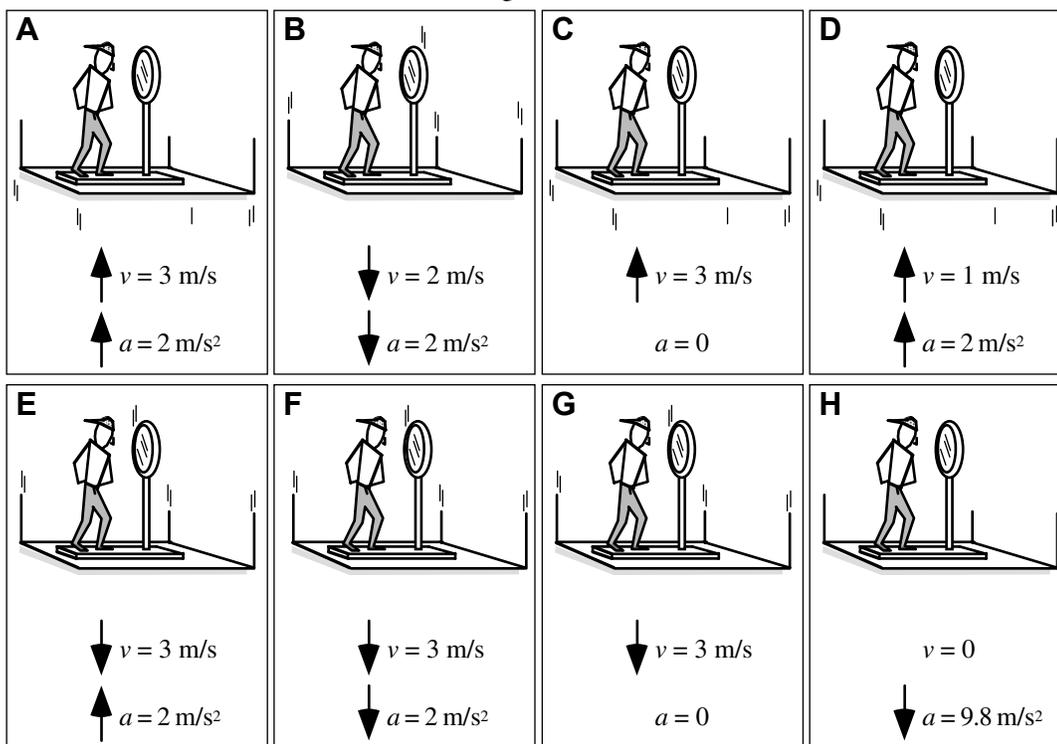
Explain your reasoning.

Answer: The scale reading will be the same in both cases.

By Newton's Second Law the net force on the person must be zero in both cases, since the elevator is not accelerating. So the normal force on the person by the scale (which is the reading on the scale) must be equal to the weight of the person in both cases.

B3-QRT63: PERSON IN AN ELEVATOR—SCALE READING

A person who weighs 500 N is standing on a scale in an elevator. The elevator is identical in all cases. The velocity and acceleration of the elevators at the instant shown are given.



(a) List the cases where the scale reading is *greater than* 500 N. _____

Explain your reasoning.

Answer: A, D, and E.

The reading on the scale will be larger than the person's weight (500 N) when he/she is being accelerated upward by the scale. When that occurs the scale has to both balance the weight of the person and provide the force to accelerate the person upward.

(b) List the cases where the scale reading is *less than* 500 N. _____

Explain your reasoning.

Answer: B, F and H.

Here the reading is less than the person's weight because the scale doesn't have to balance the whole weight of the person.

(c) List the cases when the scale reading is *equal to* the scale reading of 500 N. _____

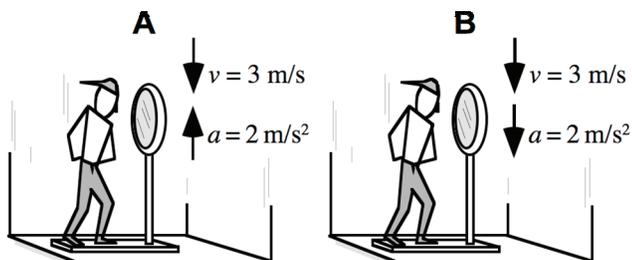
Explain your reasoning.

Answer: C and G.

Since there is no acceleration the net force has to be zero, so the scale has to balance the weight of the person.

B3-CT64: PERSON IN AN ELEVATOR MOVING DOWNWARD—SCALE READING

A person who weighs 600 N is standing on a scale in an elevator. The elevator is identical in both cases. In both cases the elevator is moving downward, but in Case A it is accelerating upward and in Case B it is accelerating downward.



Will the scale reading be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

Answer: The scale reading will be greater in Case A.

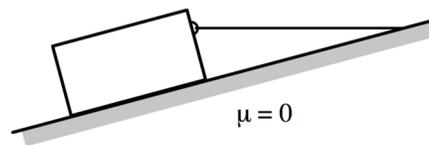
By Newton's Second Law the net force on the person must point upward in Case A since the acceleration is upward and the net force will point downward in Case B since the acceleration is downward. So the normal force on the person by the scale (which is the reading on the scale) must be larger than the weight of the person in Case A, and smaller than the weight of the person in Case B. The direction of the velocity of the elevator is not relevant to the scale reading.

B3-CT65: BLOCK HELD ON SMOOTH RAMP—WEIGHT AND NORMAL FORCE

A block is tethered to a frictionless ramp by a horizontal string as shown. The block is at rest.

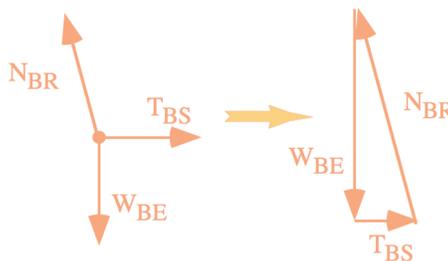
Is the normal force exerted on the block by the ramp (i) *greater than*, (ii) *less than*, or (iii) *equal to* the weight of the block? _____

Explain your reasoning.



Answer: The normal force is greater than the weight.

Since the block is at rest, the net force on the block is zero. There are three forces acting on the block, as shown in the free-body diagram, and they must add to zero as shown in the vector sum diagram. The normal force is the hypotenuse of the resulting right triangle, and must therefore be the largest force.



B3-WWT66: TWO BLOCKS AT REST—NORMAL FORCE

The two blocks are identical and both are at rest. A student comparing the normal force exerted on the block by the surface in the two cases states:

“Since both blocks are identical, I think the normal forces are the same because in each case the normal force will be equal to the weight.”

What, if anything, is wrong with this contention? If something is wrong, identify it and explain how to correct it. If this contention is correct, explain why.

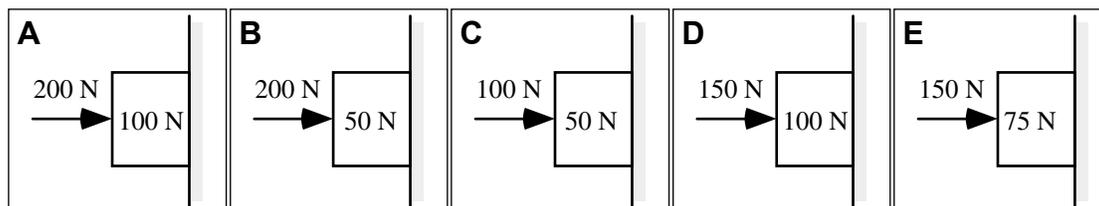


Answer: The student's contention is wrong.

The net force is equal to zero in both cases since the block is not accelerating. In the case on the left, the normal force and the weight point in opposite directions and have the same magnitude. In the case on the right, the normal force points perpendicular to the surface up and to the left and the weight points straight down. There is also a friction force pointing up and to the right, parallel to the surface. These three forces must add to zero. As can be seen in the vector sum diagram, the weight vector in this case is the hypotenuse of a right triangle, and is longer than the vector representing the normal force, which is one of the sides of this triangle.

B3-RT67: BOXES ON ROUGH VERTICAL SURFACE—NORMAL FORCE ON WALL

Boxes are held at rest against rough, vertical walls by forces pushing horizontally on the boxes as shown.



Rank the magnitude of the normal force exerted on the walls by the boxes.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>				
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

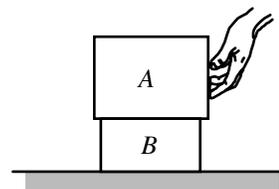
Explain your reasoning.

Answer: $A = B > D = E > C$.

The blocks are not accelerating, so the net force on each box must be zero. Since there are only two horizontal forces on each box, the applied horizontal force and the normal force on the box by the wall, these forces must be equal to each other. The normal force on the wall by the box is the Newton's Third Law pair to the normal force on the box by the wall, and is therefore equal in magnitude to the normal force on the box by the wall. So the normal force on the wall by the box is equal to the applied force in each case.

B3-QRT68: STACKED BLOCKS—NORMAL FORCES

A student pushes two blocks, A and B, across a desk at a constant speed. The force exerted on block A by the student is directed horizontally to the left. The mass of block A is greater than the mass of block B.



(a) The magnitude of the normal force exerted on block A by block B

- (i) is *greater than* the magnitude of the normal force exerted on block B by block A.
- (ii) is *less than* the magnitude of the normal force exerted on block B by block A.
- (iii) is *equal to* the magnitude of the normal force exerted on block B by block A.
- (iv) *cannot be compared* to the magnitude of the normal force exerted on block B by block A based on the information given.

Explain your reasoning.

(iii) The normal force on block A by block B must be equal to the normal force on block B by block A by Newton's Third Law.

(b) The magnitude of the normal force exerted on block A by block B

- (i) is *greater than* the magnitude of the weight of block A.
- (ii) is *less than* the magnitude of the weight of block A.
- (iii) is *equal to* the magnitude of the weight of block A.
- (iv) *cannot be compared* to the magnitude of the weight of block A based on the information given.

Explain your reasoning.

(iii) Since the net force on block A is zero, and its weight and the normal force on block A by block B are the only vertical forces, these forces must be equal in magnitude and opposite in direction.

(c) The magnitude of the normal force exerted on block B by block A

- (i) is *greater than* the magnitude of the weight of block B.
- (ii) is *less than* the magnitude of the weight of block B.
- (iii) is *equal to* the magnitude of the weight of block B.
- (iv) *cannot be compared* to the magnitude of the weight of block B based on the information given.

Explain your reasoning.

(i) The normal force on B by A is equal to the weight of A, and the weight of A is greater than the weight of B, so the normal force on B by A must be greater than the weight of B.

(d) The magnitude of the normal force exerted on block B by block A

- (i) is *greater than* the magnitude of the normal force exerted on block B by the desk.
- (ii) is *less than* the magnitude of the normal force exerted on block B by the desk.
- (iii) is *equal to* the magnitude of the normal force exerted on block B by the desk.
- (iv) *cannot be compared* to the magnitude of the normal force exerted on block B by the desk based on the information given.

Explain your reasoning.

(ii) The normal force on B by the desk must be equal to the weight of both blocks, so it is greater than the weight of block A alone, which is equal to the normal force on block B by block A.

B3-WWT69: BLOCKS ON A ROUGH INCLINE—TENSION

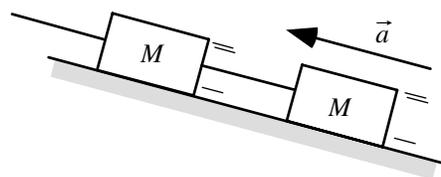
Two identical blocks are tied together with a rope and are pulled with a second rope so that they accelerate up a rough incline. A student considering the forces acting in this situation contends:

“I think the tension in the rope connecting the boxes has to be larger than the force the lower box exerts on that rope because the tension is causing the lower block to accelerate up the incline.”

What, if anything, is wrong with this contention? If something is wrong, identify it and explain how to correct it. If this contention is correct, explain why.

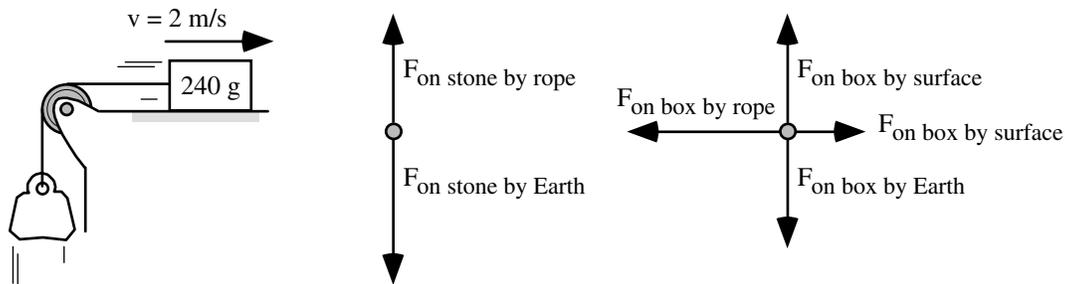
Answer: The student's contention is wrong.

Newton's Third Law requires that the force the rope exerts on the block has to be equal in magnitude to the force the block exerts on the rope.



B3-SCT70: HANGING STONE CONNECTED TO BOX—FREE-BODY DIAGRAMS

A massless rope connects a box on a horizontal surface and a hanging stone as shown below. The rope passes over a massless, frictionless pulley. The box is given a quick tap so that it slides to the right along the horizontal surface. The figure below shows the block after it has been pushed while it is still moving to the right. The mass of the hanging stone is larger than the mass of the box. There is friction between the box and the horizontal surface. Free-body diagrams that a student has drawn to scale for the box and for the hanging stone are shown.



Four students discussing these free-body diagrams make the following contentions:

Ali: “There is a problem with the free-body diagram for the hanging stone. The two forces should have the same magnitude.”

Brianna: “But the stone is moving upward—there should be a larger force in that direction.”

Carlos: “No, the diagram for the hanging stone is okay, but there is a problem with the diagram for the box. The frictional force is in the wrong direction.”

Dante: “Both free-body diagrams are correct because they show the way the objects would be accelerating.”

With which, if any, of these students do you agree?

Ali _____ Brianna _____ Carlos _____ Dante _____ None of them _____

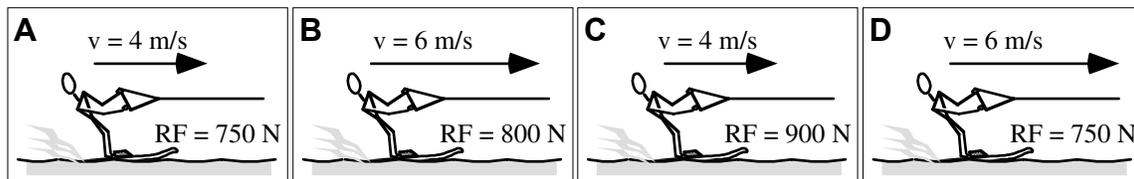
Explain your reasoning.

Answer: For the instant shown, Carlos is correct.

Since the box is sliding to the right, the friction on the box by the surface will be to the left. So all horizontal forces on the box would be to the left and the block would slow down (as we expect). If, as Ali claimed, the forces on the stone had the same magnitude, the stone would have no net force and would not accelerate, and if (as Brianna claimed) the force on the stone by the rope was greater then the stone would speed up.

B3-RT71: WATER SKIERS—TENSION

Water skiers are pulled at a constant speed by a towrope attached to a speedboat. Because the weight of the skiers and the type of skis they are using varies, they experience different resistive forces from the water. Values for this resistive force (RF) and for the speed of the skiers are given.



Rank the tension in the towrope.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

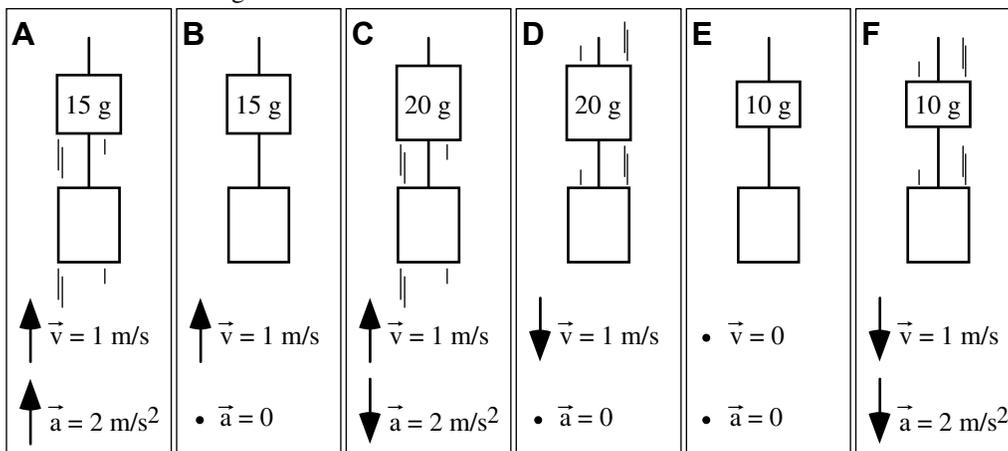
Explain your reasoning.

Answer: $C > B > A = D$.

The net force on each skier must be zero because they are not accelerating. The only horizontal forces are the tension in the ski rope and the resistive force. These must be equal and opposite to each other to give zero net force. So the ranking of the tension is the same as the ranking of the resistive force.

B3-RT72: HANGING BLOCKS—TENSION

Two blocks are connected by strings and are pulled upward by a second string attached to the upper block. The lower block is the same in all cases, but the mass of the upper block varies. The acceleration and velocity for each system at the instant shown are given.



Rank the tension in the string between the blocks.

						OR			
1	2	3	4	5	6		All	All	Cannot
Greatest					Least		the same	zero	determine

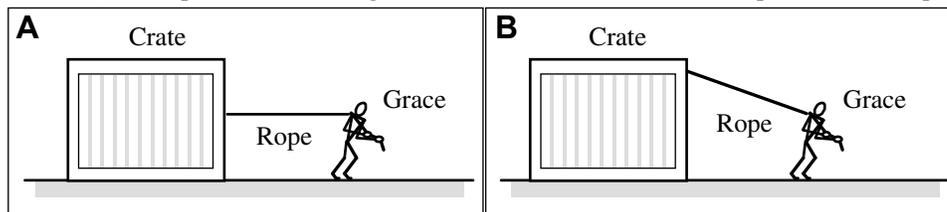
Explain your reasoning.

Answer: $A > B = D = E > C = F$.

These tensions can be compared by considering a free-body diagram of the lower block. The tension minus the weight of the lower block must equal the mass of the lower block times its acceleration in the upward direction. Since the lower blocks are all identical, the tension must be greatest for blocks that are accelerating upward, less for blocks with no acceleration, and least for blocks that are

B3-CT73: PULLING A CRATE ACROSS FLOOR—APPLIED FORCE

In both cases below, Grace pulls the same large crate across a floor at a constant speed of 1.48 m per second.



Is the magnitude of the force exerted by Grace on the rope (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

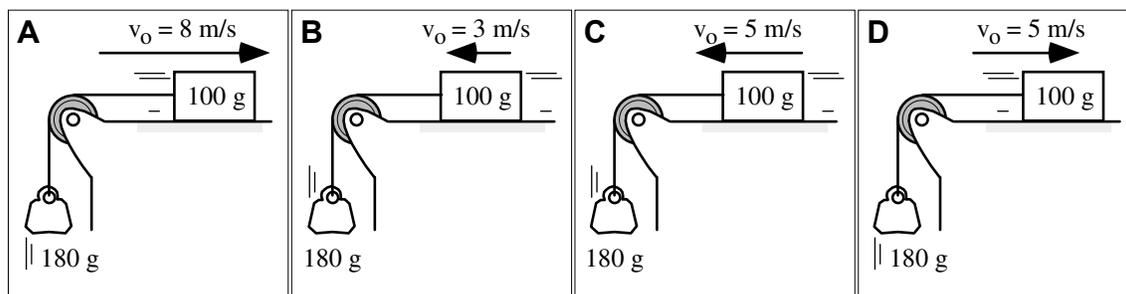
Explain your reasoning.

Answer: Greater in case B.

Since the force that the rope exerts on the crate in case B has a downward vertical component, and the net vertical force is zero (the crate has a constant velocity), the normal force on the crate by the floor is larger than the weight of the crate in case B. In case A, however, the normal force on the crate by the floor is equal to the weight. Since the normal force on the crate by the floor is greater in case B than in case A, the friction force is also greater in case B than in case A. So it must be true that the horizontal component of the tension is greater in case B than in case A, since the net horizontal force is zero (the crate has a constant velocity). The tension in case B is greater than its horizontal component, and the horizontal component of this tension is greater than the tension in case A, so the tension in case B is greater than the tension in case A.

B3-RT74: HANGING STONE CONNECTED TO BOX ON ROUGH SURFACE—ACCELERATION

In each case shown below, a box is sliding along a horizontal surface. There is friction between the box and the horizontal surface. The box is tied to a hanging stone by a massless rope running over a massless, frictionless pulley. All these cases are identical except for the different initial velocities of the boxes.



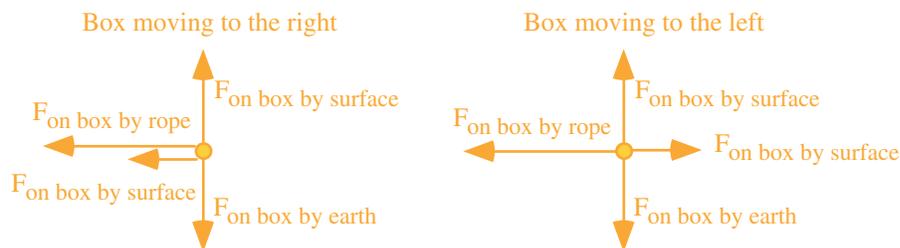
Rank the magnitudes of the accelerations of the boxes at the instant shown.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

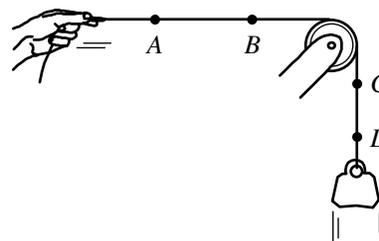
Answer: $A = D > B = C$.

Since the surfaces are identical and the blocks all have the same mass, the magnitude of the friction force is the same in all cases. However, when the box is moving to the left the frictional force is to the right (opposite the direction of the tension force on the box) and when the box is moving to the right the frictional force is to the left, in the same direction as the tension. The friction force doesn't depend on the velocity. The acceleration is the same for all boxes that are moving in the same direction, since the free-body diagrams for these boxes will be the same.



B3-RT75: MOVING STRING PASSING OVER A PULLEY—TENSION AT POINTS

A student pulls on a massless string that passes over a frictionless pulley and is attached to a suspended mass. He is pulling the string horizontally so that, at the instant shown, the mass is moving upward at a constant speed.



Rank the tension at the labeled points.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

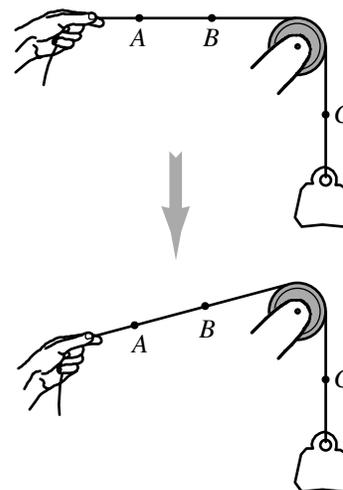
Explain your reasoning.

Answer: All the same.

In the approximation that the string is massless, any small section of the string must have no net force acting on it (since it is not accelerating). So the tension on one end of that small section must have the same magnitude as the tension on the other end. By extension, the tension must be the same everywhere along the horizontal section of string and everywhere along the vertical section of string. The tension in the horizontal section of string exerts a counterclockwise torque on the pulley, and the tension in the vertical section of string exerts a clockwise torque on the pulley. Since the pulley has no angular acceleration, the net torque on it is zero. The tension in the horizontal portion of the string between the pulley and the hand must be equal to the tension in the vertical portion of the string between the pulley and the mass. The tension in the horizontal portion of the string between the pulley and the hand must be equal to the tension in the vertical portion of the string between the pulley and the mass, and the pulley pivot is the radius of the pulley, and is the same for both sections of string.)

B3-SCT76: STRING AT ANGLE PASSING OVER A PULLEY—TENSION AT POINTS

A student holds a massless string that passes over a frictionless pulley and is attached to a suspended mass as shown. The mass is at rest. She then moves her hand so that the portion of string between her hand and the pulley moves from the horizontal to an angle as shown. Four students make the following contentions about this situation:



Aletheia: “The tensions would all stay the same. The pulley will change the direction of the force, but the size of the force only depends on the mass, and that hasn’t changed.”

Bem: “Nothing has changed at point C, and the tension will stay the same there. But A and B are being pulled downward now as well as horizontally, so the tensions at A and B would increase.”

Charity: “I agree with you that the tension at point C would stay the same, but I think the tensions at A and B would actually decrease. Now gravity is actually helping the hand to keep the mass in place, and so the hand won’t have to pull as hard. Since A and B are close to where the hand is pulling, the tension there will go down.”

Dorothy: I think the tension will increase at all three points. As the hand moves down so that it is more vertical, it’s like it is fighting the pull of the mass more and more. So the string gets stretched tighter—the tension goes up all over.”

With which, if any, of these students do you agree?

Aletheia _____ Bem _____ Charity _____ Dorothy _____ None of them _____

Explain your reasoning.

Answer Aletheia is correct.

In the approximation that the string is massless, any small section of the string must have no net force acting on it (since it is not accelerating). So the tension on one end of that small section must have the same magnitude as the tension on the other end. By extension, the tension must be the same everywhere along the string. This is also true for the tension on one side of the pulley compared to the tension on the other side: Since the pulley has no net torque on it, the counterclockwise torque due to the tension in the string between the pulley and the hand must be equal to the clockwise torque on the pulley due to the tension in the vertical portion of the string. (The perpendicular distance between the line of action of the tension force and the pulley pivot is the same for both sections of string.) The tensions at A, B, and C are the same.

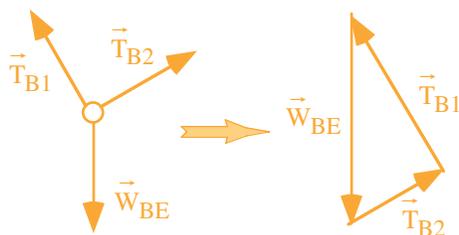
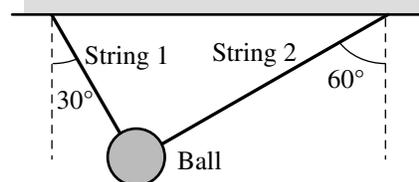
B3-CT77: BALL SUSPENDED FROM CEILING BY TWO STRINGS—TENSION

A 0.5-kg ball is suspended from a ceiling by two strings. The ball is at rest.

(a) Is the tension in string 1 (i) *greater than*, (ii) *less than*, or (iii) *the same as* the tension in string 2? _____

Explain your reasoning.

Answer: Greater since the forces on the ball must add to zero. Keeping the directions of the vectors as shown constrains the relative sizes of T_{B1} and T_{B2} as shown in the vector summation here. Note that T_{B1} and T_{B2} are perpendicular. So, T_{B1} must be greater than T_{B2} .



Suppose that the ceiling in the picture above is the ceiling of an elevator, and that the elevator is moving *down* at a constant speed of 2 m/s.

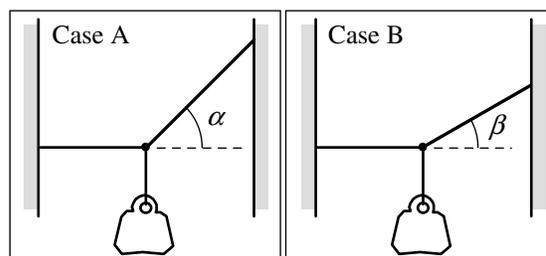
(b) Is the tension in string 1 (i) *greater than*, (ii) *less than*, or (iii) *the same as* the tension in string 1 in the previous question (a) where the ball was at rest? _____

Explain your reasoning.

Answer: The forces are the same as for the same system at rest. The net force is still zero since the ball is moving at a constant speed. The weight does not change (the ball is still on the surface of the earth) and so the tensions will not change.

B3-SCT78: HANGING MASS—TENSION IN THREE STRINGS

A hanging mass is suspended midway between two walls. The string attached to the left wall is horizontal while the string attached to the right wall makes an angle with the horizontal as shown. This angle (α) in Case A is larger than the angle (β) in Case B. Four students make the following claims about the tensions in the strings:



Abbie: “I think the tensions in any string in Case A is going to be the same as the equivalent string in Case B. The weight is the same, and the weight is still going to be divided up among the three ropes.”

Bobby: “I think the tensions in the horizontal and vertical strings are the same, because they are exactly the same in both cases. But in Case B the diagonal rope is shorter, so the tension is more concentrated there.”

Che: “The diagonal string still has to hold the weight up by itself, because the horizontal string can’t lift anything. So the diagonal string still has the same tension. But in Case B it’s pulling harder against the horizontal string because of the angle, so the tension in the horizontal string has to go up.”

Damian: “But the diagonal string is fighting harder against the weight in Case A—it is pointing more nearly opposite the weight. So it has to have a greater tension in Case A. And since the tension in the diagonal string is greater, and the tension in the vertical string is the same, the tension in the horizontal string must be less in Case A. The tensions still have to balance out so that they are the same in both cases.”

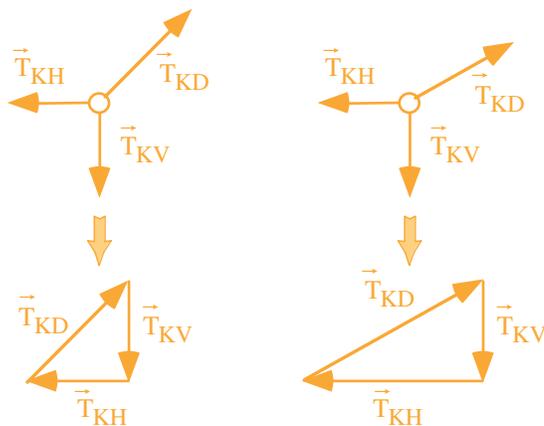
With which, if any, of these students do you agree?

Abbie _____ Bobby _____ Che _____ Damian _____ None of them _____

Explain your reasoning.

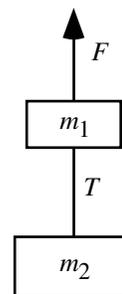
Answer: None of these responses is correct.

The weight is the same for both cases, and because the weight is at rest we can conclude from a free-body diagram of the weight that the tension in the vertical string must be the same in both cases. But since the knot connecting the strings is at rest in both cases vector sum of forces acting on the knot is zero in both cases. Comparing vector sums, (with subscripts K, H, V, and D for knot, horizontal, vertical, and diagonal) we can see that the horizontal tension must be greater in case B. The tension in the diagonal string will also be larger in case B.



B3-SCT79: TWO CONNECTED OBJECTS ACCELERATING DOWNWARD—TENSION

Two objects with masses of $m_1 = 6$ kg and $m_2 = 10$ kg are connected by a massless string. They are pulled upward by an applied force F . Since this force is smaller than the total weight of the objects, there is a constant downward acceleration of 3 m/s². The tension in the string connecting the objects is T . Four students discuss this tension:



Anh: “The tension in the string is the net force on the lower object. Using Newton’s Second law, we get $F_{\text{net}} = ma = 30$ N for the tension, since the lower object has a mass of 10 kg and it is accelerating at 3 m/s².”

Brandon: “The tension in the string is more than the net force of 30 N since the lower object has a weight of about 100 N. The tension should be 130 N since the 30 N, the net force, is added to 100 N, the weight.”

Cathy: “The tension in the string is upward and should be less than the weight since the system is accelerating downward. It should be 70 N by applying Newton’s Second law and taking into account the directions of the forces.”

Deshi: “We cannot answer it until we know which direction the system is moving. Is it moving upward or downward? Won’t that make a big difference on the tension?”

With which, if any, of these students do agree?

Anh _____ Brandon _____ Cathy _____ Deshi _____ None of them _____

Explain your reasoning.

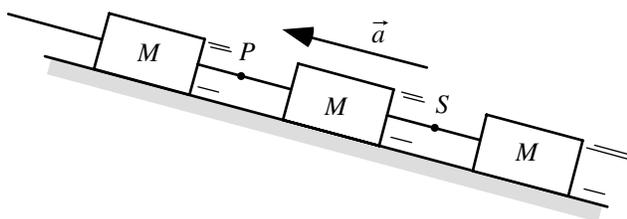
Answer: Cathy is correct.

From a free-body diagram for the lower mass, and choosing up as the positive direction, we can apply Newton’s 2nd Law to the lower mass. The tension T minus the weight of the lower mass equals the mass m_2 times its acceleration. $F_{\text{net}}(\text{on } m_2) = m_2 a = (10\text{kg})(-3 \text{ m/s}^2) = -30 \text{ N}$. So $T - m_2 g = T - (10\text{kg})(10\text{m/s}^2)$ or $+98 \text{ N} - 30 \text{ N} = T = 70\text{N}$.

B3-WWT80: BLOCKS ON A SMOOTH INCLINE—TENSION

Three identical blocks are tied together with ropes and pulled up a smooth (frictionless) incline. The blocks accelerate up the incline. A student who is asked to compare the tension in the rope at point P to the tension at point S states:

“Each rope is pulling one block. All three blocks are accelerating at the same rate and they are identical. I think the tensions at points P and S will be the same.”



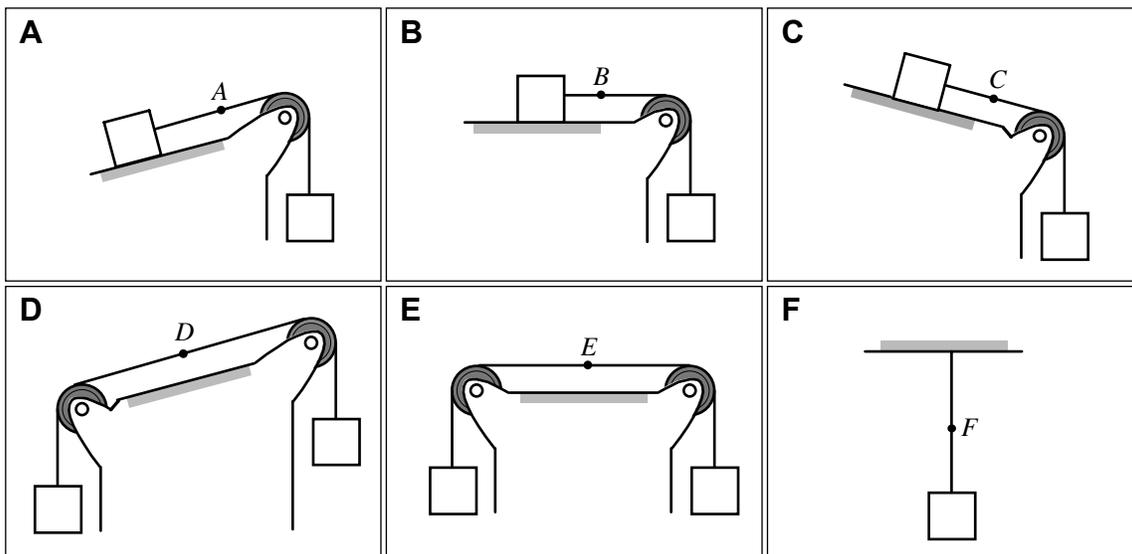
What, if anything, is wrong with this contention? If something is wrong, identify it and explain how to correct it. If this contention is correct, explain why.

Answer: The student's contention is incorrect.

From a free-body diagram of the lower block, the tension at point S must be larger than the component of the weight of that block that is parallel to the ramp in order for the lower block to accelerate up the ramp. From a free-body diagram of the middle block, the tension at point P must be larger than the tension at point S plus the component of the weight of the middle block that is parallel to the ramp in order for the middle block to accelerate up the ramp. So the tension at P must be greater than the tension at S .

B3-RT81: HANGING MASS—STRING TENSION

A massless string is attached to one or more identical blocks at rest. All the pulleys are frictionless and massless.



Rank the tension in the strings at the labeled points.

						OR			
1	2	3	4	5	6		All the same	All zero	Cannot determine
Greatest				Least					

Explain your reasoning.

Answer: The tensions at all of the labeled points are the same. For a massless string, the tension is the same at all points along the string. A free-body diagram of any hanging block will have a tension force upward and a 10-N weight downward, so the tension in all strings is 10 Newtons.

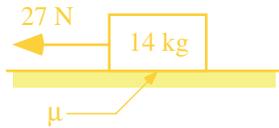
B3-WBT82: NEWTON'S SECOND LAW EQUATION—PHYSICAL SITUATION

The equation below results from the application of Newton's Laws to an object:

$$27 \text{ N} - (\mu)(14 \text{ kg})(9.8 \text{ m/s}^2) = 0$$

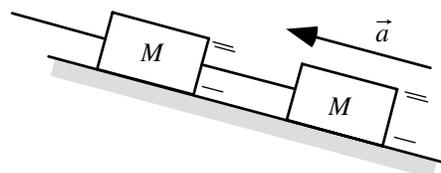
Draw a physical situation that would result in this equation, and explain how your drawing is consistent with the equation.

Answer: One possibility is a 14 kg object sitting at rest on a horizontal surface with friction. There also is a 27 N force on the object that is applied parallel to the surface which is less than the maximum static friction force.



B3-SCT83: BLOCKS ON A SMOOTH INCLINE—TENSION

Two blocks are tied together with a rope and are pulled so that they accelerate up a smooth (frictionless) incline. Three students are comparing the tension in the rope between the blocks to the magnitude of the force that the lower block exerts on that rope:



Alberto: “I think the tension has to be larger because it is causing the lower block to accelerate up the incline. If it was the same, then the block wouldn’t accelerate.”

Benifacio: “I disagree. Force equals mass times acceleration, and the accelerations of the rope and the lower block are the same. The rope hardly weighs anything compared to the block, so it can’t exert as much force. The force the block exerts has to be greater.”

Connie: “I agree that the rope and the block have exactly the same acceleration since they are moving together. But I think that means that the force has to be the same.”

With which, if any, of these students do you agree?

Alberto ___ Benifacio ___ Connie ___ None of them ___

Explain your reasoning.

Answer: None of these students is correct.

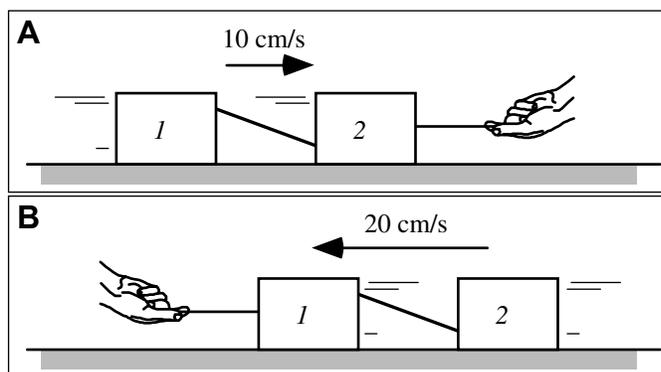
Connie is correct that the forces being compared are equal in magnitude, but her reasoning is incorrect. The force that the lower block exerts on the rope and the tension force that the rope exerts on the block are a Newton’s Third Law pair, and so they must have equal magnitudes.

B3-CT84: BLOCKS MOVING AT CONSTANT SPEED—TENSION IN CONNECTING STRING

Two identical blocks, 1 and 2, are connected by a massless string. In Case A, a student pulls on a string attached to block 2 so that the blocks travel to the right across a desk at a constant speed of 10 cm/s. In Case B, the student pulls on a string attached to block 1 so that the same blocks travel across the same desk to the left at a constant speed of 20 cm/s.

Will the tension in the diagonal string connecting the two blocks be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

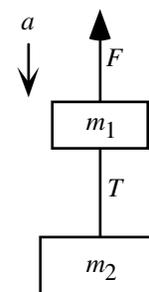


Greater in case A.

In both cases the net force acting on the trailing block is zero, since that block is moving at a constant speed. In case A, the tension in the connecting string has a component acting downward, on the trailing block, and since the net vertical force is zero, the normal force must be greater than the weight. In case B, the tension in the connecting string has a component acting upward on the trailing block, and the normal force on the block must therefore be less than the weight. Since the friction on the trailing block by the desk is proportional to the normal force on that block, the friction force on the block by the desk is greater in Case A than it is in Case B. And since the frictional force on the trailing block is equal to the horizontal component of the tension in the string connecting the blocks in both cases, the tension in this string must be greater in Case A than in Case B.

B3-LMCT85: TWO CONNECTED OBJECTS ACCELERATING DOWNWARD—TENSION IN STRING

Two objects with masses of $m_1 = 6$ kg and $m_2 = 10$ kg are connected by a massless string. They are pulled upward by an applied force F . Since this force is smaller than the total weight of the objects, there is a constant downward acceleration of 3 m/s^2 . The tension in the string connecting the objects is labeled T .



Identify from choices (i)–(iv) how each change described below will affect the tension (T) in the string between the objects.

Compared to the case above, this change will:

- (i) *increase* the tension in the string.
- (ii) *decrease* the tension in the string but not to zero.
- (iii) *decrease* the tension in the string **to zero**.
- (iv) *have no effect* on the tension in the string.
- (v) *have an indeterminate* effect on the tension in the string.

All of these modifications are the only changes to the initial situation shown in the diagram.

(a) The mass of m_1 is decreased to 5 kg and the mass of m_2 is increased to 11 kg. _____
 Explain your reasoning.

Answer (i). Altering m_1 has no effect on the tension. Increasing m_2 will require a larger tension for the same acceleration with an increased weight. T goes from 68 N to 74.8 N.

(b) The mass of m_1 is increased to 7 kg and the mass of m_2 is decreased to 9 kg. _____
 Explain your reasoning.

Answer (ii). Altering m_1 has no effect on the tension. Decreasing m_2 will require a smaller tension for the same acceleration & decreased weight. T goes from 68 N to 61.2 N.

(c) The applied force F is increased and the acceleration is 2 m/s^2 downward. _____
 Explain your reasoning.

Answer (i). The tension T is the weight of m_2 minus the net force— m_2 times the acceleration due to gravity—as required by Newton’s second law. T goes from 68 N to 78 N.

(d) The applied force F is increased and the acceleration is 4 m/s^2 upward. _____
 Explain your reasoning.

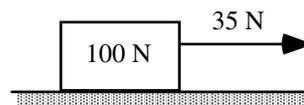
Answer (i). The increase in the acceleration due to the increase in the applied force will require that the tension increase. In this case, T goes from 68 N to 138 N.

(e) The applied force F is decreased and the acceleration is 4 m/s^2 downward. _____
 Explain your reasoning.

Answer (ii). The increase in the acceleration due to the decrease in the applied force will require that the tension decrease. In this case, T goes from 68 N to 58 N.

B3-SCT86: BOX PULLED ON ROUGH, HORIZONTAL SURFACE—FRICTIONAL FORCE ON BOX

A 100 N box is initially at rest on a rough, horizontal surface. The coefficient of static friction is 0.6, and the coefficient of kinetic friction is 0.4. A constant 35 N horizontal force to the right is applied to the box. Four students are discussing the frictional force exerted on the box by the rough surface 1 second after the force is first applied:



Al: “The frictional force is 60 N since the box will not be moving and the coefficient of static friction is 0.6 with a normal force of 100 N.”

Brianna: “The frictional force is 40 N since the coefficient of kinetic friction is 0.4 and there is a normal force of 100 N.”

Carlos: “The frictional force is 35 N since the box will not be moving and the frictional force will cancel out the applied force of 35 N.”

David: “It is 40 N for the kinetic frictional force and 60 N for the static frictional force. The normal force is 100 N and the coefficient of kinetic friction is 0.4, giving 40 N for the kinetic friction. Similarly, for the static frictional force it is 60 N since it has a coefficient of static friction of 0.6.”

With which, if any, of these students do you agree?

Al _____ Brianna _____ Carlos _____ David _____ None of them _____

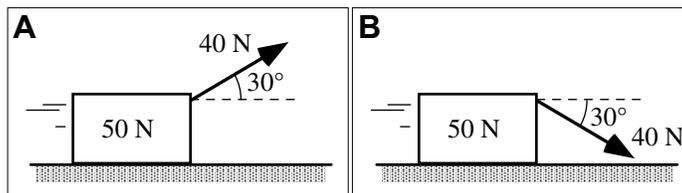
Explain your reasoning.

Answer: Carlos is correct.

The applied force is less than 60 N, the amount needed to get the box moving, so it is still at rest. The static frictional force remains at 35 N and opposes the applied force of 35 N.

B3-CT87: BOX MOVING OVER HORIZONTAL SURFACE—FRICTIONAL FORCE ON BOX

A 50 N box has an applied force on it of 40 N that makes an angle of 30° with the horizontal. The box is moving to the right at a constant speed in both cases.



Will the frictional force exerted on the box by the rough surface be (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

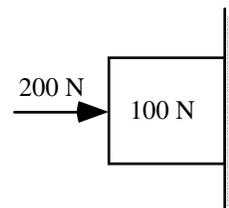
Explain your reasoning.

Answer: Greater in case B.

The boxes are not accelerating vertically, so the net vertical force must be zero. The tension in the string in Case A has an upward vertical component, reducing the normal force required to balance the weight of the box. In Case B the tension has a downward vertical component, so the normal force must be greater than the weight. Since the force of friction is proportional to the normal force, the frictional force is greater in case B.

B3-SCT88: BOX HELD AGAINST VERTICAL SURFACE—FRICTIONAL FORCE ON BOX

A constant horizontal force on a 200 N is applied to a box in contact with a vertical surface. The coefficient of static friction between the box and the surface is 0.6, and the coefficient of kinetic friction is 0.4. Several students are discussing the frictional force on the box 1 second after the force is first applied:



Art: “The frictional force is 60 N since the box will not be moving and the coefficient of static friction is 0.6.”

Bratislav: “The frictional force is 100 N upward since the box has a weight of 100 N downward.”

Celeste: “The frictional force will be 120 N since the box will not be moving and the normal force will be 200 N.”

Dorothy: “The frictional force will be 40 N for the kinetic frictional force and 60 N for the static frictional force. The weight is 100 N and the coefficient of kinetic friction is 0.4, giving 40 N for the kinetic friction. Likewise, for the static frictional force it has a coefficient of static friction of 0.6, giving a static frictional force of 60 N.”

With which, if any, of these students do you agree?

Art _____ *Bratislav* _____ *Celeste* _____ *Dorothy* _____ None of them _____

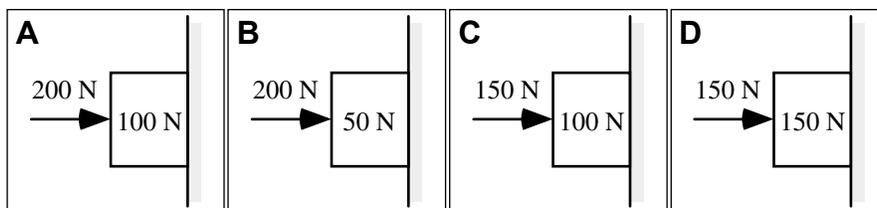
Explain your reasoning.

Answer: Bratislav is correct.

The coefficient of static friction is 0.6, so the maximum static frictional force is 0.6 times the normal force acting to the left on the box by the vertical surface. Since the box is not moving horizontally, this normal force must have the same magnitude as the horizontal applied force, 200 Newtons. The maximum frictional force will then be 120 Newtons. This is greater than the weight of the box, so the box will not slip downward. The static frictional force will be less than its maximum possible value, and will equal 100 Newtons, keeping the box at rest.

B3-RT89: BOXES HELD AGAINST VERTICAL SURFACES—FRICTIONAL FORCES ON THE WALL

A box is held at rest against a rough, vertical surface by a force pushing horizontally as shown. Values for the applied force and the weight of the boxes are given. The boxes are all made of the same material and the walls are identical.



Rank the magnitude of the frictional force exerted on the wall by these boxes.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

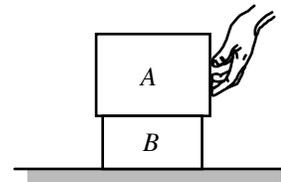
Explain your reasoning.

Answer: $D > A = C > B$.

The frictional force on the box by the wall is equal to the weight of each box since they are at rest. The net force must be zero on each box, and the friction force must have the same magnitude as the weight and be in the opposite direction. The friction force on the wall by the box is the Newton's Third Law pair to the friction force on the box by the wall, and has the same magnitude, so the friction force on the wall by the box has the same magnitude as the weight of the box.

B3-QRT90: MOVING STACKED BLOCKS—FRICTION FORCES

A student pushes two blocks across a desk at a constant speed. The force exerted on block A by the student is directed horizontally to the left. The mass of block A is greater than the mass of block B.



(a) The magnitude of the friction force exerted on block A by block B

- (i) is *greater than* the magnitude of the friction force exerted on block B by block A.
- (ii) is *less than* the magnitude of the friction force exerted on block B by block A.
- (iii) is *equal to* the magnitude of the friction force exerted on block B by block A.
- (iv) cannot be compared to the magnitude of the friction force exerted on block B by block A based on the information given.

Explain your reasoning.

(iii) The magnitude of the friction force on block B by block A must be equal to the magnitude of the friction force on block A by block B by Newton's Third Law.

(b) The magnitude of the friction force exerted on block B by the desk

- (i) is *greater than* the magnitude of the friction force exerted on block B by block A.
- (ii) is *less than* the magnitude of the friction force exerted on block B by block A.
- (iii) is *equal to* the magnitude of the friction force exerted on block B by block A.
- (iv) cannot be compared to the magnitude of the friction force exerted on block B by block A based on the information given.

Explain your reasoning.

(iii) Since block B is moving at a constant speed, the net horizontal force acting on it must be zero, so the friction force on B by A must be equal in magnitude and opposite in direction to the friction force on B by desk.

(c) The magnitude of the friction force exerted on block A by block B

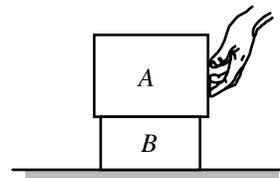
- (i) is *greater than* the magnitude of the force exerted on block A by the hand.
- (ii) is *less than* the magnitude of the force exerted on block A by the hand.
- (iii) is *equal to* the magnitude of the force exerted on block A by the hand.
- (iv) cannot be compared to the magnitude of the force exerted on block A by the hand based on the information given.

Explain your reasoning.

(iii) Since block A is moving at a constant speed, the net horizontal force acting on it must be zero, so the friction force on A by B must be equal in magnitude and opposite in direction to the force on A by the hand.

B3-QRT91: STACKED BLOCKS SLOWING DOWN—FRICTION FORCES

A student pushes two blocks across a desk. At the instant shown, the blocks are *slowing down*. The force exerted on block A by the student is directed horizontally to the left. The mass of block A is greater than the mass of block B.

**(a) The magnitude of the friction force exerted on block A by block B**

- (i) is *greater than* the magnitude of the friction force exerted on block B by block A.
- (ii) is *less than* the magnitude of the friction force exerted on block B by block A.
- (iii) is *equal to* the magnitude of the friction force exerted on block B by block A.
- (iv) cannot be compared to the magnitude of the friction force exerted on block B by block A based on the information given.

Explain your reasoning.

(iii) The friction force on block B by block A must be equal to the friction force on block A by block B by Newton's Third Law.

(b) The magnitude of the friction force exerted on block B by the desk

- (i) is *greater than* the magnitude of the friction force exerted on block B by block A.
- (ii) is *less than* the magnitude of the friction force exerted on block B by block A.
- (iii) is *equal to* the magnitude of the friction force exerted on block B by block A.
- (iv) cannot be compared to the magnitude of the friction force exerted on block B by block A based on the information given.

Explain your reasoning.

(i) Since block B is slowing down, the net horizontal force acting on it must be directed to the right, so the friction force on B by the desk must be greater in magnitude and opposite in direction to the friction force on B by A.

(c) The magnitude of the friction force exerted on block A by block B

- (i) is *greater than* the magnitude of the force exerted on block A by the hand.
- (ii) is *less than* the magnitude of the force exerted on block A by the hand.
- (iii) is *equal to* the magnitude of the force exerted on block A by the hand.
- (iv) cannot be compared to the magnitude of the force exerted on block A by the hand based on the information given.

Explain your reasoning.

(i) Since block A is slowing down, the net horizontal force acting on it must be directed to the right, so the friction force on A by B must be greater in magnitude and opposite in direction to the force on A by the hand.

B3-WWT92: TWO ASTEROIDS—GRAVITATIONAL FORCE ON EACH

Two asteroids with masses of m and $3m$ exert gravitational forces on each other. A student contends that the forces will be in different directions and of different magnitudes as shown below.



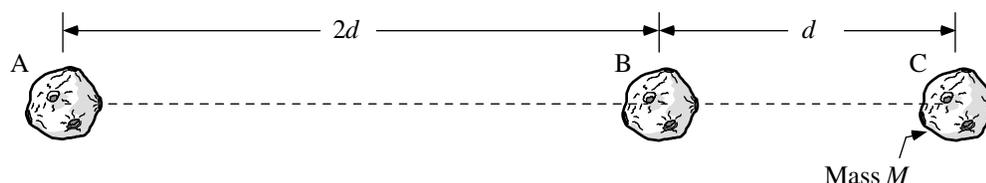
What's wrong, if anything, with this student's contention? If something is wrong, identify it and explain how to correct it. If this student's contention is correct, explain why.

Answer: The forces are attractive so the directions should be reversed and the forces should be equal as required by Newton's Third Law.



B3-SCT93: THREE ASTEROIDS IN A LINE—CALCULATION OF MASS

At the instant shown, three asteroids are in a line, and the distance between A and B is twice the distance between B and C. Asteroid C has mass M . There is no net force on asteroid B due to the other asteroids.



Three students are discussing how they might find the mass of asteroid A:

Ari: “We don’t really have enough information to find the mass of A. Since there’s no net force on B, the force from A has to cancel the force from C. To find the force on B from C, we’d use Newton’s law of universal gravitation. But since the force is proportional to the product of the masses, we’d need to know both masses.”

Bira: “I don’t think we really need the mass of B. Asteroid A is twice as far away as C, so if it also has a mass M it will exert half as much force as C does. Since it has to exert the same force for the net force on B to be zero, it has to have twice the mass.”

Cole: “It’s true that A pulls on B to the left, and C pulls on B to the right. But you can’t just use Newton’s law of universal gravitation, because that only allows you to calculate the force between two masses. Here there are three masses, and asteroid A is exerting some of its force on B and some on C.”

With which, if any, of these students do you agree?

Ari ____ **Bira** ____ **Cole** ____ None of them ____

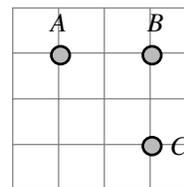
Explain your reasoning.

Answer: None of the students are correct, but Bira comes close.

The force on B due to each of the other asteroids is proportional to the mass of B, as Ari states. However, if the mass of B were to increase by some factor, the force acting on it from each of the other asteroids would increase by that same factor, and the net force on it would still be zero. Bira’s reasoning is correct except that the force due to each asteroid is proportional to the inverse square of the distance. Since asteroid A is twice as far away from B as C is, it would only exert one-quarter the force if it had mass M . Asteroid A must have a mass $4M$ in order for the net force on B to be zero. Cole is correct that the universal law of gravitation only allows you to calculate the force between two masses, but once you have used this law to calculate the force between each pair of masses, the force on any individual mass is just the vector s

B3-QRT94: THREE OBJECTS EXERTING GRAVITATIONAL FORCES—NET FORCE

Three objects each with a mass of M exert gravitational forces on each other. Which of the arrows below shows the direction of the net force on mass B ?



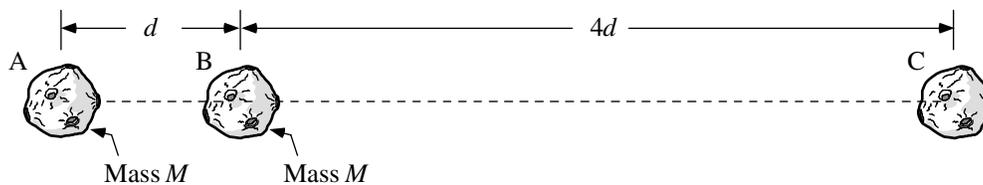
- (i)  (ii)  (iii)  (iv)  (v) None of these

Explain your reasoning.

Answer (a) vector addition of the force on B by A (which is directed horizontally to the left) and the force on B by C (which is directed toward the bottom of the page or down) results in a force 45° down to the left.

B3-WWT95: THREE ASTEROIDS IN A LINE—MASS OF ASTEROID

At the instant shown, three asteroids are in a line, and the distance between B and C is 4 times as large as the distance between A and B. Asteroids A and B have the same mass. There is no net force on asteroid B due to the other two asteroids.



A student makes the following comment about the mass of asteroid C:

“Since C is four times as far from B as A is, it is only going to have one-quarter the effect on B. To get the forces on B to balance, you’d need the mass of C to be four times as large.”

What, if anything, is wrong with the student’s statement? If nothing is wrong, state that explicitly, and explain why it is correct. If the statement is incorrect, state what is wrong and how you would correct it.

Answer: The statement is incorrect.

The gravitational force on one asteroid by another is proportional to the product of the masses and inversely proportional to the square of the distance between the centers of mass. If asteroid C had the same mass as asteroid A, the force C exerts on B would only be one-sixteenth the magnitude of the force that A exerts on B. For the magnitude of the force that C exerts on B to be the same as the magnitude of the force that A exerts on B, the mass of C has to be sixteen times the mass of A. The two forces acting on B would then be equal in magnitude and opposite in direction, and the net force on B would be zero.

B3-QRT96: TWO OBJECTS—GRAVITATIONAL FORCE ON EACH

Object A has twice the mass of Object B.

$2m$

m

○
A

●
B

Identify the pair of force vectors (the arrows) that correctly compare the gravitational force exerted on A by B with the gravitational force exerted on B by A.

	Gravitational force on A by B	Gravitational force on B by A
(a)		
(b)		
(c)		
(d)		
(e)		
(f)		

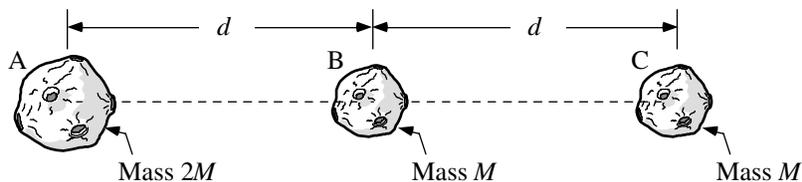
Explain your reasoning.

Answer; (b).

The forces must be attractive, because the gravitational force is always an attractive force. Newton's Third Law requires that the magnitude of the forces be the same.

B3-RT97: THREE ASTEROIDS IN A LINE—NET FORCE

At the instant shown, three asteroids are in a line, and the distance between A and B is the same as the distance between B and C. Asteroids B and C have the same mass, while asteroid A has twice the mass.



Rank the magnitude of the net force on each asteroid due to the other two asteroids.

<input style="width: 90%; height: 90%;" type="text"/>	<input style="width: 90%; height: 90%;" type="text"/>	<input style="width: 90%; height: 90%;" type="text"/>	OR	<input style="width: 90%; height: 90%;" type="text"/>	<input style="width: 90%; height: 90%;" type="text"/>	<input style="width: 90%; height: 90%;" type="text"/>
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

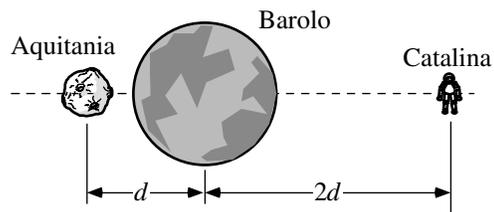
Answer: $A > C > B$.

The gravitational force on one asteroid by another is proportional to the product of the masses and inversely proportional to the square of the distance between the centers of mass. If we let the force on B by C have magnitude F then the force on A by B will have magnitude $2F$ since A has twice the mass. The force on A by C will have magnitude one-half F because the distance is doubled and mass is doubled. Free-body diagrams for the three asteroids are shown below. In terms of F , the magnitude of the net force on A is $2.5F$; on B it is F ; and on C it is $1.5F$.



B3-WWT98: ASTRONAUT NEAR A PLANET AND A MOON—GRAVITATIONAL FORCE

At the instant shown, Catalina, an astronaut, is in space a distance $2d$ from the planet Barolo. A moon of Barolo, Aquitania, is a distance d on the other side of Barolo. A physics student trying to calculate the gravitational force on Catalina states:



“We only need to worry about the planet Barolo, not its moon. Since Catalina is on the other side of Barolo, the gravitational field due to Aquitania is blocked by Barolo. The only force acting on Catalina is the gravitational force due to Barolo, which we can find using Newton’s law of universal gravitation.”

What, if anything, is wrong with the student’s statement? If nothing is wrong, state that explicitly, and then explain why it is correct. If the statement is incorrect, state what is wrong and how you would correct it.

Answer: The statement is incorrect.

The gravitational force between two objects is the same whether there is mass between the objects or not. To find the net force on Catalina, we would need to use Newton’s Law of Universal Gravitation to find the force on Catalina due to Barolo, then do the same to find the force on Catalina due to Aquitania, then add these forces to find the net force.

B3-CT99: ASTRONAUT NEAR A MOON—GRAVITATIONAL FORCE

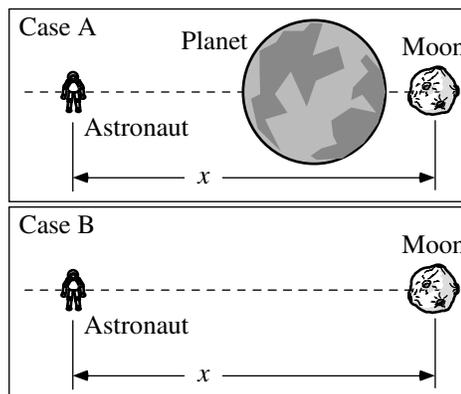
In both cases shown at right, an astronaut is a distance x from a moon. The two cases are identical except that in Case A there is a large planet directly between the astronaut and the moon.

Is the gravitational force on the astronaut by the moon (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

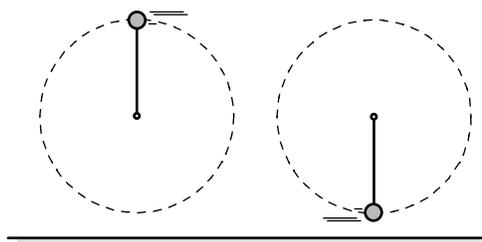
Answer: The same in both cases.

The gravitational force between two objects is the same whether there is mass between the objects or not. Newton's Law of Universal Gravitation will give the force on the astronaut due to the moon in both cases.



B3-SCT100: BALL WHIRLED IN VERTICAL CIRCLE—NET FORCE ON BALL

A ball with a weight of 2 N is attached to the end of a cord of length 2 m. The ball is whirled in a vertical circle counterclockwise. The tension in the cord at the top of the circle is 7 N, and at the bottom it is 15 N. (The speed of the ball is not the same at these points.)



(a) Three students discuss the net force on the ball at the top.

Angelica: “The net force on the ball at the top position is 7 N since the net force is the same as the tension.”

Bo: “The net force on the ball at the top position is 9 N. Both the tension and the weight are acting downward so you have to add them.”

Charles: “No, you are both wrong. You need to figure out the centripetal force (mv^2/r) and include it in the net force.”

With which, if any, of these students do you agree?

Angelica _____ Bo _____ Charles _____ None of them _____

Explain your reasoning.

Answer: Bo is correct, as can be seen by drawing a free-body diagram for the ball. The tension acts downward at the top (the cord cannot push on the ball!) and the weight is also downward, toward the center of the earth. So the net force at the top is the vector sum of these two forces acting in the same direction and has a magnitude of 9 N.

(b) Now the students discuss the net force on the ball at the bottom.

Angelica: “The net force on the ball at the bottom position is 15 N since the net force is the same as the tension.”

Bo: “The net force on the ball at the bottom position is 17 N, since you need to add the weight of 2 N to the tension of 15 N.”

Charles: “The net force on the ball at the bottom position is 13 N. I agree that you need to take into account both the weight and the tension, but they are in different directions so they will subtract.”

With which, if any, of these students do you agree?

Angelica _____ Bo _____ Charles _____ None of them _____

Explain your reasoning.

Answer: Charles is correct, as can be seen by drawing a free-body diagram for the ball. The tension is upward and the weight is still downward, and the vector sum of these two forces must point toward the center of the circle. The magnitude of the net force is the vector sum of these two oppositely directed forces and has a magnitude equal to 15 N minus 2 N or 13 N.

B3-CT101: SKATEBOARDER ON CIRCULAR BUMP—WEIGHT AND NORMAL FORCE

A skateboarder is skating over a circular bump. At the instant shown, she is at the top of the bump and is moving with a speed of 5 m/s.

Is the normal force exerted on the skateboarder by the bump (i) *greater than*, (ii) *less than*, or (iii) *equal to* the weight of the skateboarder? _____

Explain your reasoning.

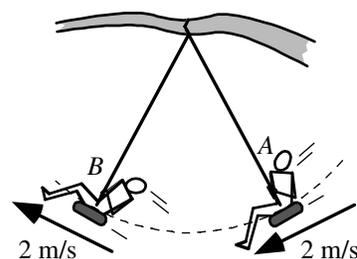


Answer: The normal force is less than the weight.

Since the skateboarder is moving along a circular path, there is an acceleration toward the center of the circle, or downward. Therefore the net force must point down, and the weight must be greater than the normal force.

B3-SCT102: CHILD ON A SWING—TENSION

A child is swinging back and forth on a tire swing that is attached to a tree branch by a single rope. Shown are two positions during a swing from right to left. Three students are discussing the tension in the rope at the bottom of the swing.



Alia: “At the bottom of the swing, she will be moving exactly horizontally. Since she is not moving vertically at that instant, the vertical forces cancel. The tension in the rope at that instant equals the weight.”

Brian: “Just looking at the velocity vectors, the change in velocity points upward between A and B. So that is the direction of the acceleration, and also of the net force. To get a net force pointing upward, the tension would have to be greater than the weight.”

Clara: “But there aren’t just two forces acting on her at the bottom of the swing. Since she’s moving in a circle, there’s also the centripetal force, which acts toward the center of the circle. Since both the tension and the centripetal force point upward, and the weight points downward, to get zero net force the tension actually has to be less than the weight. The tension plus the centripetal force equals the weight.”

With which, if any, of these students do you agree?

Alia _____ *Brian* _____ *Clara* _____ None of them _____

Explain your reasoning.

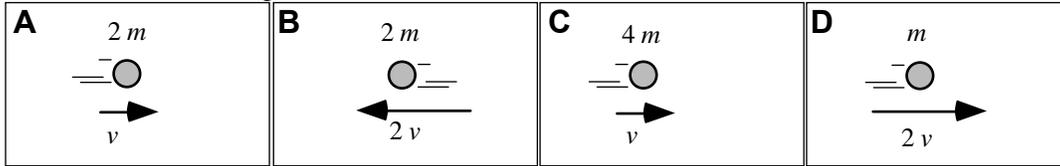
Answer: Brian is correct.

The average acceleration must be in the direction of the change in velocity from A to B, which is upward. So the net force points upward, and therefore the tension must be greater than the weight. Clara is treating the centripetal force as if it were a separate force, when in this case the force acting toward the center is the tension.

B4 WORK AND ENERGY

B4-RT01: MOVING BALLS I—KINETIC ENERGY

In the figures below, balls are traveling in different directions. The balls have the same size and shape, but they have different masses and are traveling at different velocities as shown.



Rank the kinetic energy of the balls.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

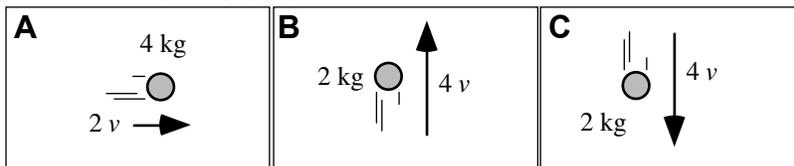
Explain your reasoning.

Answer: $B > C = D > A$

Based on the definition of kinetic energy as the product of the mass and the square of the velocity, which is a scalar since it is the dot product of the velocity with itself.

B4-RT02: MOVING BALLS II—KINETIC ENERGY

In the figures below, balls are traveling in different directions. The balls have the same size, mass, and shape, but they are traveling with different velocities as shown.



Rank the kinetic energy of the balls.

<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3		All	All	Cannot
Greatest		Least		the same	zero	determine

Explain your reasoning.

Answer: $B = C > A$

Based on the definition of kinetic energy as the product of the mass and the square of the velocity.

B4-WWT03: OBJECT CHANGING VELOCITY—WORK

A 2-kg object accelerates as a net force acts on it. During the 5 seconds this force acts, the object changes its velocity from 3 m/s east to 7 m/s west.



A student states:

“The initial kinetic energy of the object was 9 Joules, and the final kinetic energy was 49 Joules. Thus the change in kinetic energy of this object during these 5 seconds was 40 J, and thus the work done on this object by the net force during this period was also 40 J.”

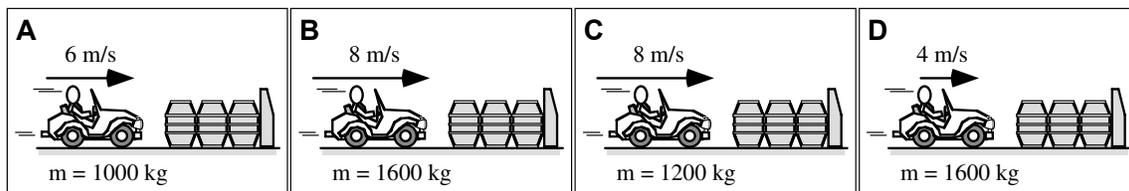
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's answer is correct.

The initial kinetic energy of the object was 9 Joules, and the final kinetic energy was 49 Joules. The change in kinetic energy was 40 Joules. Since the change in kinetic energy is equal to the net work done on the object, the net work must also be 40 Joules.

B4-RT04: CARS AND BARRIERS—STOPPING FORCE IN SAME DISTANCE

Cars that are moving along horizontal roads are going to be stopped by plowing into barrel barriers. All of the cars are the same size and shape, but they are carrying loads with different masses. All of the cars are going to be stopped in the same distance.



Rank the strength (magnitude) of the forces that will be needed to stop the cars in the same distance.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

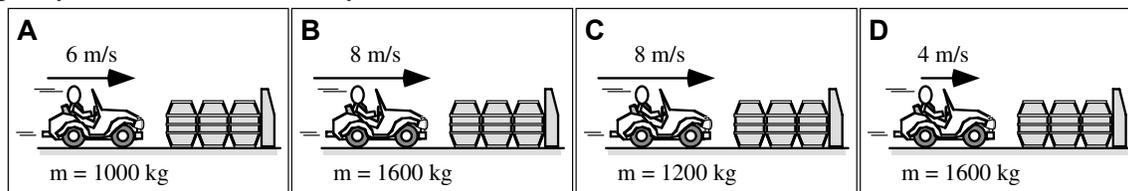
Explain your reasoning.

Answer: $B > C > A > D$.

The product of the stopping (average) force and the distance through which it acts is the work done on the cars. That work will go into changing the kinetic energy of the cars. Since they are all stopping, i.e., zero final kinetic energy, in the same distance the ranking is based on the initial kinetic energies of the cars

B4-RT05: CARS AND BARRIERS—STOPPING DISTANCE WITH THE SAME FORCE

Cars that are moving along horizontal roads are going to be stopped by plowing into identical barriers. All of the cars are the same size and shape, but they are carrying loads with different masses. All of the cars are going to be stopped by the same constant force by the barrier.



Rank the distance that will be needed to stop the cars with the same force.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

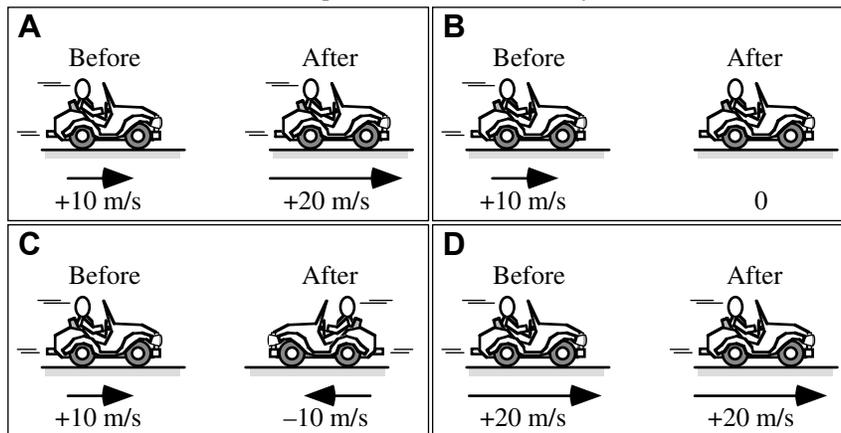
Explain your reasoning.

Answer: $B > C > A > D$.

The same force acting through different distances will be the work needed to stop each car. The work of the applied force will change the kinetic energy from the initial value to zero for each car, so the ranking is determined by the initial kinetic energies.

B4-RT06: CARS CHANGING VELOCITY—WORK DONE

The situations below show before and after "snapshots" of a car's velocity. All cars have the same mass.



Rank the work done on the cars to create these changes in velocity for the same distance traveled.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

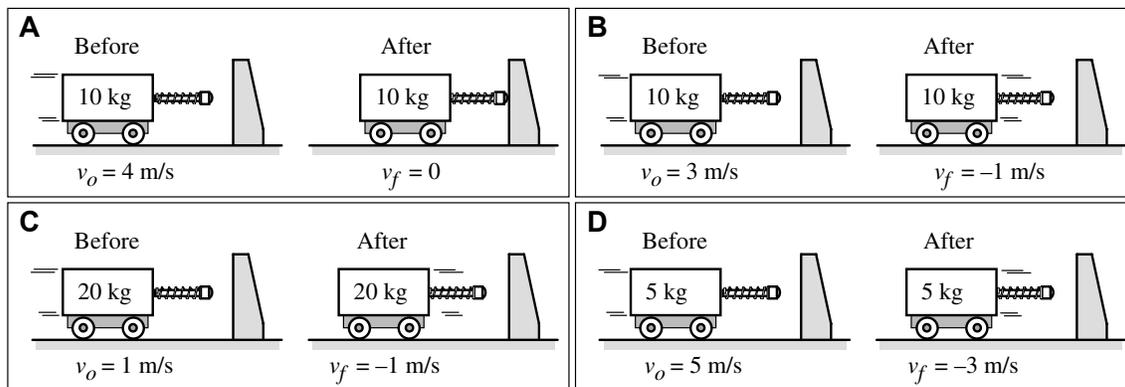
Explain your reasoning.

Answer: A > C = D > B.

The work in these situations changes the kinetic energy of the cars, which here is determined by the difference in the squares of the speeds, final minus initial. Since all cars have the same mass, the car with the greatest change in the squares of the speeds had the greatest energy change through working.

B4-RT07: BOUNCING CART—CHANGE IN KINETIC ENERGY

A cart with a spring plunger runs into a fixed barrier. The mass of the cart, its velocity just before impact with the barrier, and its velocity just after collision are given in each figure. (All velocities before the collision are given as positive since the cart is moving to the right. After the collision the cart is either moving to the left, indicated with a negative velocity, or is at rest.)



Rank the change in kinetic energy for each cart.

<input style="width: 90%;" type="text"/>	OR	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

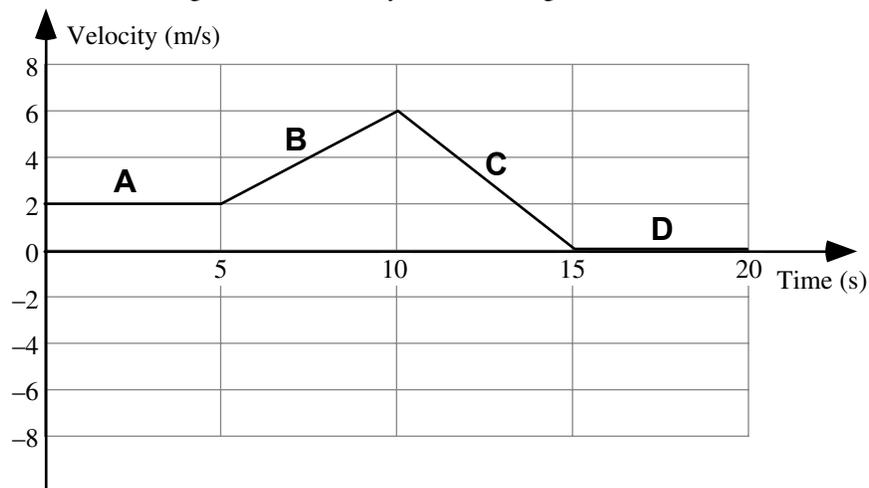
Explain your reasoning.

Answer: A > B = D > C.

The change in kinetic energy is the final minus the initial which gives the sequence here since kinetic energy is a scalar and we are only interested in the change.

B4-RT09: VELOCITY-TIME GRAPH I—WORK DONE ON BOX

Shown below is a graph of velocity versus time for an object that moves along a straight, horizontal line under the perhaps intermittent action of a single force exerted by an external agent.



Rank the work done on the box by the external agent for the 5-second intervals shown on the graph.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

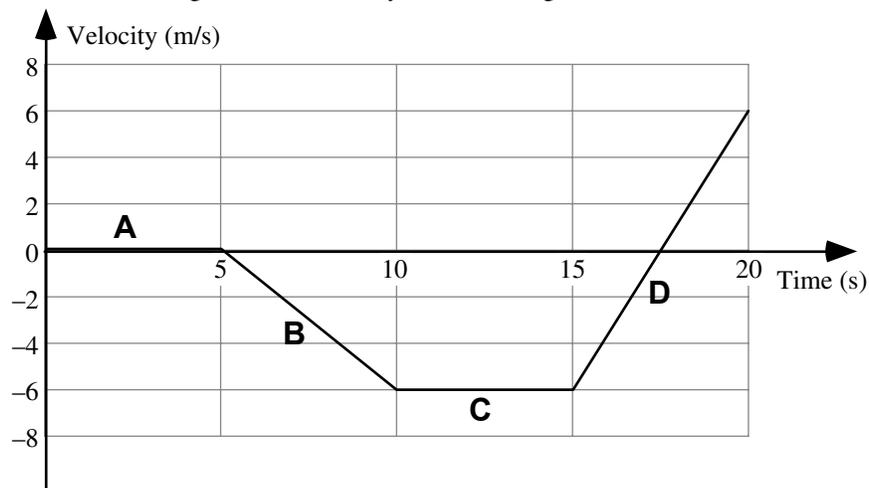
Explain your reasoning.

Answer: $B > A = D > C$.

In this situation the work done on the box will change its kinetic energy, so to find how much work was done we need to subtract the initial kinetic energy from the final value for each 5 second interval. The external agent will do positive work in interval B, no work in intervals A and D since the kinetic energy doesn't change in those intervals, and negative work in interval C, i.e., the box is doing work on the external agent in C rather than the agent doing work on the box.

B4-RT10: VELOCITY-TIME GRAPH II—WORK DONE ON BOX

Shown below is a graph of velocity versus time for an object that moves along a straight, horizontal line under the perhaps intermittent action of a single force exerted by an external agent.



Rank the work done on the box by the external agent for the 5-second intervals shown on the graph.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

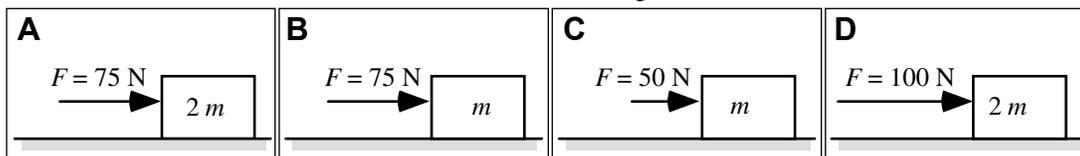
Explain your reasoning.

Answer: $D > A = C > B$.

In this situation the work done on the box will change its kinetic energy, so to find how much work was done we need to subtract the initial kinetic energy from the final value for each 5 second interval. The external agent will do positive work in interval D, no work in intervals A, and C since the kinetic energy doesn't change in those intervals, and negative work in interval B, i.e., the box does work on the external agent in B rather than the agent doing work on the box.

B4-RT11: FORCE PUSHING BOX—CHANGE IN KINETIC ENERGY

A box is pushed 10 m across a floor in each case shown. All boxes have an initial velocity of 10 m/s to the right. The mass of the box and the net horizontal force for each case are given.



Rank the change in kinetic energy of the boxes.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

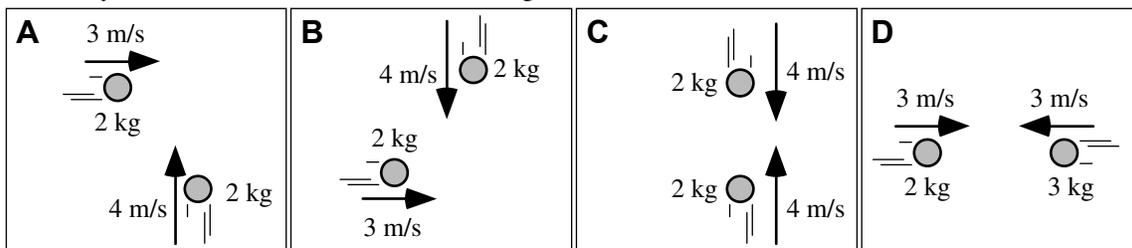
Explain your reasoning.

Answer: $D > A = B > C$.

The change in kinetic energy will occur because of the energy transfer produced by the external agent working on the box, so, since all of the boxes move the same distance under the action of the external force, the magnitudes of the external forces determine the ranking.

B4-QRT12: TWO BALL SYSTEMS—KINETIC ENERGY OF SYSTEM

In the figures below, systems of two balls are traveling in different directions. The balls are identical in size and shape, but they have different masses and are traveling at different velocities as shown.



Rank the total kinetic energy of the two-ball systems before they interact.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

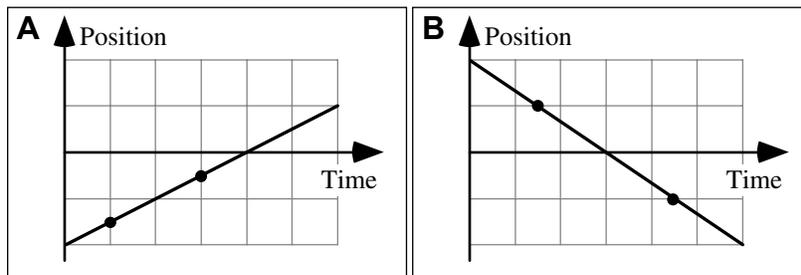
Explain your reasoning.

Answer: C > A = B > D

Since KE is a scalar compute the $KE = \frac{1}{2}mv^2$ for each ball and add them together. For A, the total is $9\text{ J} + 16\text{ J} = 25\text{ J}$; for B also 25 J ; for C, 32 J but note the momentum is zero; and for D, $9\text{ J} + 27/2\text{ J} = 22.5\text{ J}$

B4-WWT13: BOAT POSITION-TIME GRAPHS—WORK

Shown are graphs of the position versus time for two boats traveling along a narrow channel. The scales on both axes are the same for the graphs. In each graph, two points are marked with dots.



A student who is using these graphs to compare the net work done on the two boats between the two points says:

“I think that more net work was done on the boat in graph B because it moved farther during the interval between the points.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

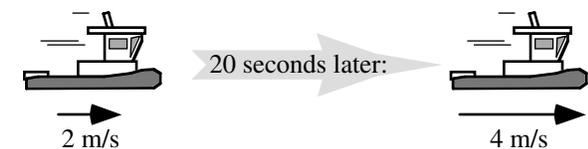
Answer: The student’s contention is wrong.

Since both graphs have a straight line for the motion of the sailboats, they moved at constant speeds, so there was no change in their kinetic energy and, consequently, no work was done on them.

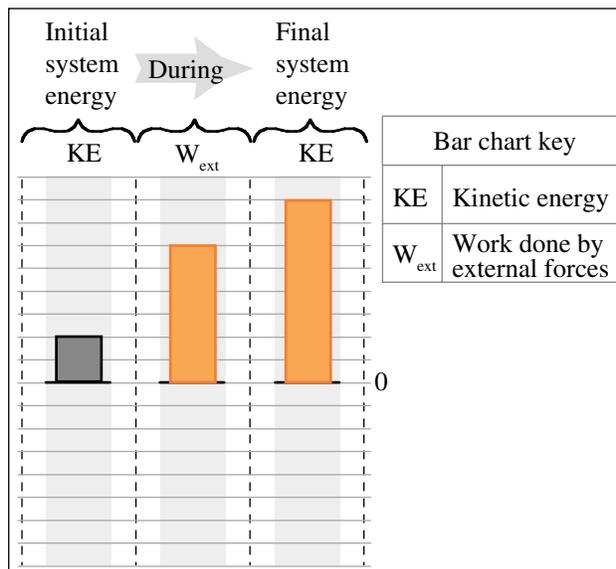
B4-BCT14: TUGBOAT CHANGING VELOCITY I—WORK & KINETIC ENERGY BAR CHART

(a) The velocity of a tugboat increases from 2 m/s to 4 m/s in the same direction while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

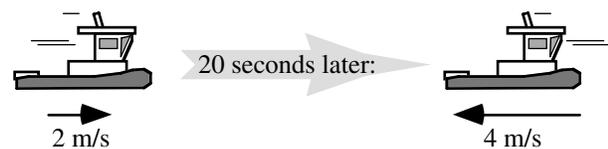


Explain.

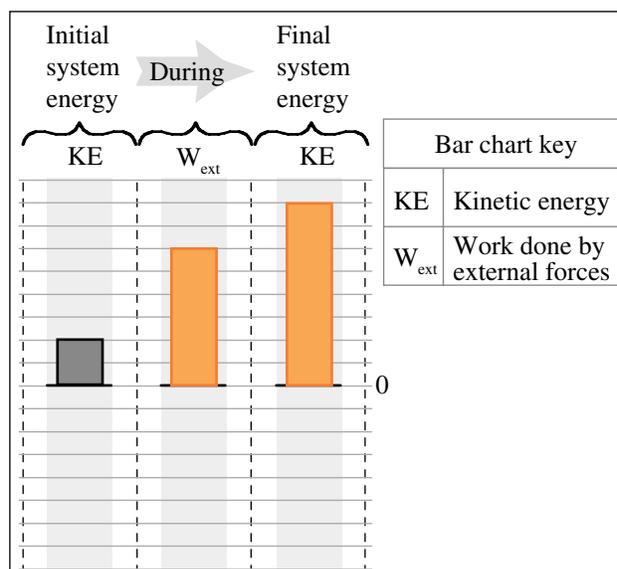


(b) The velocity of a tugboat changes from 2 m/s to 4 m/s in the opposite direction while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.



Explain.



Answers (a) and (b) will have the same bar chart graphs. In both cases, the speed of the tugboat doubles and so the kinetic energy quadruples. In both cases, the same net work will have been done on the tugboat.

B4-BCT15: OBJECT CHANGING VELOCITY I—WORK AND KINETIC ENERGY BAR CHART

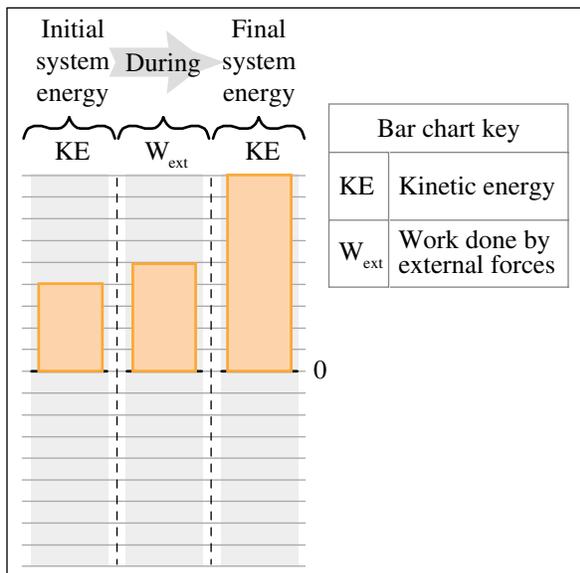
A 2-kg object changes its velocity as a force acts on it for 5 seconds. It changes its velocity from 4 m/s east to 6 m/s east as shown.



Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

Explain your reasoning.

The agent exerting the force works on the object increasing its kinetic energy.



B4-BCT16: OBJECT CHANGING VELOCITY II—WORK AND KINETIC ENERGY BAR CHART

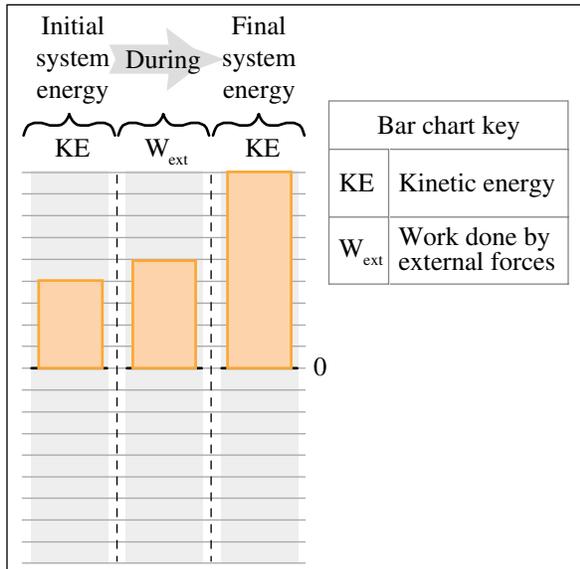
A 2-kg object changes its velocity as a force acts on it for 5 seconds. It changes its velocity from 4 m/s east to 6 m/s west as shown.



Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.

Explain your reasoning.

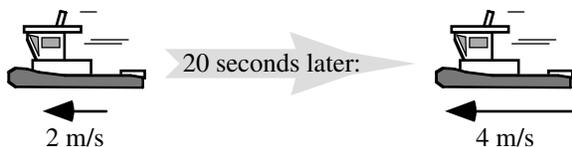
The agent exerting the force works on the object increasing its kinetic energy.



B4-BCT17: TUGBOAT CHANGING VELOCITY II—WORK AND KINETIC ENERGY BAR CHART

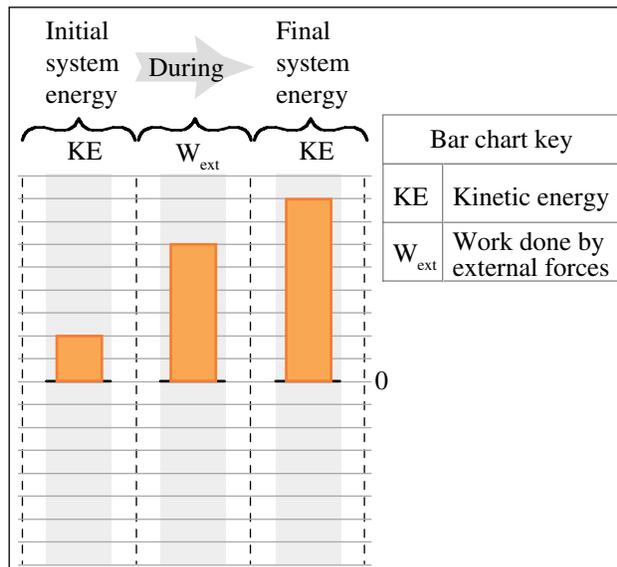
(a) The velocity of a tugboat changes from 2 m/s west to 4 m/s west while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.



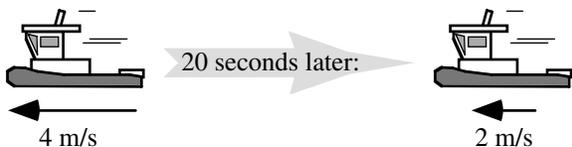
Explain.

Answer: Since the speed has doubled, the final kinetic energy will be four times larger than the initial kinetic energy. Positive work must have been done on the tugboat.



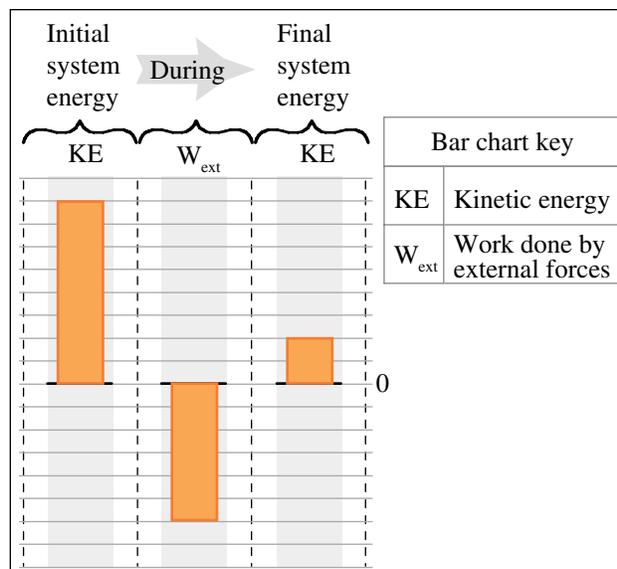
(b) The velocity of a tugboat changes from 4 m/s west to 2 m/s west while a force is applied to the tugboat for 20 seconds.

Complete the work and kinetic energy bar chart for this process. The bar heights should be in correct proportion to one another.



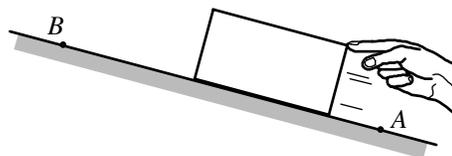
Explain.

Answer: Since the speed has halved, the final kinetic energy must be one-quarter the initial kinetic energy. Negative work must have been done on the tugboat.



B4-LMCT18: BLOCK PUSHED ON INCLINE—WORK DONE

A block is pushed so that it moves up a ramp at constant speed.



Identify from choices (i)–(iv) below the appropriate description for the work done by the specified force while the block moves from point A to point B.

- (i) is *zero*.
- (ii) is *less than zero*.
- (iii) is *greater than zero*.
- (iv) could be *positive or negative* depending on the choice of coordinate systems.
- (v) *cannot be determined*.

(a) The work done on the block by the hand. _____

Explain your reasoning.

Answer: iii, greater than zero.

The force by the hand has a component in the same direction as the displacement, so the work done is positive.

(b) The work done on the block by the normal force from the ramp. _____

Explain your reasoning.

Answer: i, zero.

The normal force is always perpendicular to the displacement, so the product of force and the component of the displacement parallel to the force is zero.

(c) The work done on the block by friction. _____

Explain your reasoning.

Answer: ii, less than zero.

The angle between the friction force and the displacement is 180° , so the product of magnitude of the frictional force and the component of the displacement parallel to the frictional force is negative.

(d) The work done on the block by the gravitational force. _____

Explain your reasoning.

Answer: ii, less than zero.

The angle between the gravitational force and the displacement is greater than 90° , so the product of the magnitude of the gravitational force and the component of the displacement parallel to the gravitational force is negative.

(e) The net work done on the block. _____

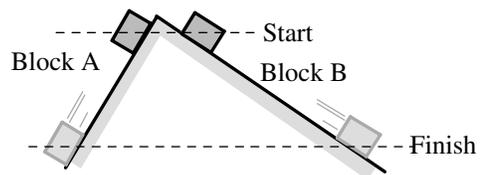
Explain your reasoning.

Answer: i, zero.

The block is moving at a constant speed, so there is no change in kinetic energy. From the work-kinetic energy theorem, the net work done equals the change in kinetic energy.

B4-SCT19: BLOCKS SLIDING DOWN FRICTIONLESS RAMPS—WORK BY THE NORMAL FORCE

Two identical blocks are released from rest at the same height. Block A slides down a steeper ramp than Block B. Both ramps are frictionless. The blocks reach the same final height indicated by the lower dashed line. Three students are comparing the work done on the two blocks by the normal force:



Annika: “I think the normal force doesn’t do any work on either block. The force on the block by the ramp is perpendicular to the ramp, and the displacement is parallel to the ramp. So the dot product is zero.”

BoBae: “Work is force times displacement. The work done on Block A is negative, while the work done on Block B is positive, because the displacement for B is in the positive direction, while the displacement for A is in the negative direction.”

Craig: “Since work is force times distance, and the distance the block travels is greater for Block B, the work done is greater for Block B.”

With which, if any, of these students do you agree?

Annika _____ *BoBae* _____ *Craig* _____ None of them _____

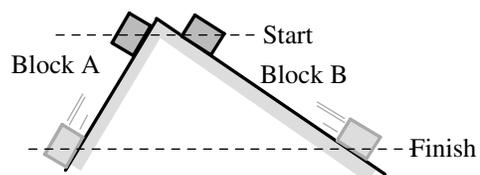
Explain your reasoning.

Answer: Annika is correct.

Work is the product of the magnitude of the force and the component of the displacement parallel to the force, and if the force is perpendicular to the displacement, the work done by that force is zero.

B4-SCT20: BLOCKS SLIDING DOWN FRICTIONLESS RAMPS—WORK BY THE EARTH

Two identical blocks are released from rest at the same height. Block A slides down a steeper ramp than Block B. Both ramps are frictionless. The blocks reach the same final height indicated by the lower dashed line. Three students are comparing the work done on the two blocks by the gravitational force (the weight of the blocks):



Asmita: “Work is related to the product of force and displacement, and the weight is the same since the blocks are identical. But Block B travels farther, so more work is done on Block B by the gravitational force than on Block A.”

Ben: “Both blocks fall the same vertical distance, so the work done is the same.”

Cocheta: “By Newton’s third law, the force exerted on the block by Earth is exactly cancelled by the force exerted on Earth by the block. The work done is zero.”

Danae: “The work depends on the angle that the force makes with the displacement. If we put the displacement and force vectors tail-to-tail, the angle is smaller for Block B than for Block A, and so the work done is greater.”

With which, if any, of these students do you agree?

Asmita _____ Ben _____ Cocheta _____ Danae _____ None of them _____

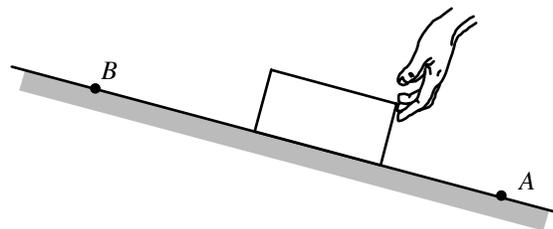
Explain your reasoning.

Answer: Ben is correct.

Work is the product of the magnitude of the force and the component of the displacement parallel to the force, and the force in both cases here is straight down. The work done by the earth is equal to $mgL\cos\theta$, where θ is the angle that the ramp makes with the vertical and L is the distance traveled down the ramp. But $L\cos\theta$ is also the vertical distance between the dashed lines, which is the same for both blocks.

B4-QRT21: BLOCK ON RAMP WITH FRICTION—WORK

A block is pushed at constant speed up a ramp from point *A* to point *B*. The direction of the force on the block by the hand is horizontal. There is friction between the block and the ramp. The distance between points *A* and *B* is 1 m.



(a) The work done on the block by the hand as the block travels from point *A* to point *B*

- (i) is zero.
- (ii) is *negative*.
- (iii) is *positive*.
- (iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

*Answer: (iii) The work done on the block by the hand is positive because the angle between the horizontal force applied by the hand and the displacement from *A* to *B* is less than 90° .*

(b) The work done on the block by the normal force from the ramp as the block travels from point *A* to point *B*

- (i) is zero.
- (ii) is *negative*.
- (iii) is *positive*.
- (iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

*Answer: (i) The work done on the block by the normal force from the ramp is zero because the angle between the normal force from the ramp and the displacement from *A* to *B* is equal to 90° .*

(c) The work done on the block by the friction force from the ramp as the block travels from point *A* to point *B*

- (i) is zero.
- (ii) is *negative*.
- (iii) is *positive*.
- (iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

*Answer: (ii) The work done on the block by the friction force on the block by the ramp is negative because the angle between the friction force and the displacement from *A* to *B* is greater than 90° .*

(d) The work done on the block by the gravitational force of the earth as the block travels from point *A* to point *B*

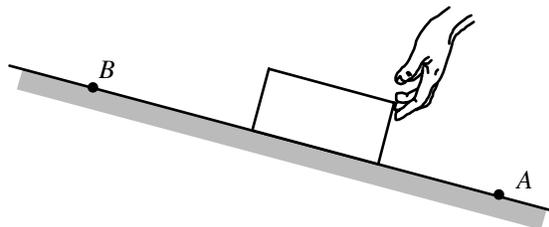
- (i) is zero.
- (ii) is *negative*.
- (iii) is *positive*.
- (iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

*Answer: (ii) The work done on the block by the gravitational force of the earth is negative because the angle between the gravitational force and the displacement from *A* to *B* is greater than 90° .*

B4-QRT22: BLOCK ON RAMP WITH FRICTION—WORK AND ENERGY

A block is pushed at constant speed up a ramp from point *A* to point *B*. The direction of the force on the block by the hand is horizontal. There is friction between the block and the ramp. The distance between points *A* and *B* is 1 m.

**(a) The kinetic energy of the block at point *B***

- (i) is *greater than* the kinetic energy of the block at point *A*.
- (ii) is *less than* the kinetic energy of the block at point *A*.
- (iii) is *equal to* the kinetic energy of the block at point *A*.
- (iv) *cannot be compared* to the kinetic energy of the block at point *A* unless we know the height difference between *A* and *B*.

Explain your reasoning.

Answer: (iii) equal

*The kinetic energy of the block is the same at *A* and *B* since the speed is constant.*

(b) The net work done on the block as it travels from point *A* to point *B*

- (i) is *zero*.
- (ii) is *negative*.
- (iii) is *positive*.
- (iv) *could be positive or negative* depending on the choice of coordinate systems.

Explain your reasoning.

Answer: (i) greater

*Using the work-kinetic energy theorem, since the change in kinetic energy of the block is zero, from point *A* to point *B*, the net work done on the block must be zero.*

(c) The work done on the block by the hand as the block travels from point *A* to point *B*

- (i) is *equal* to 1 m times the magnitude of the force exerted on the block by the hand.
- (ii) is *greater than* 1 m times the magnitude of the force exerted on the block by the hand.
- (iii) is *less than* 1 m times the magnitude of the force exerted on the block by the hand but not zero.
- (iv) is *zero*.
- (v) *cannot be compared* to the magnitude of the force exerted on the block by the hand based on the information given.

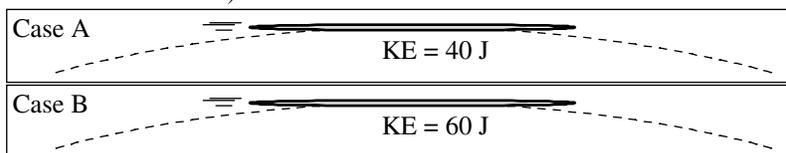
Explain your reasoning.

Answer: (iii) less than

The work done on the block by the hand is less than the product of the magnitude of this force and the magnitude of the displacement (one meter) because the force and the displacement are not parallel to one another, and the work done is therefore equal to the magnitude of the force times the magnitude of the

B4-CT23: THROWN JAVELINS—HORIZONTAL FORCE

Shown are two javelins (light spears) that have been thrown at targets. We are viewing the javelins when they are in the air about halfway to landing. Both javelins have the same mass, but they have different kinetic energies as shown. (Ignore air resistance for this task.)



Is the horizontal force acting on the javelin in Case A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the horizontal force acting on the javelin in Case B? _____

Explain your reasoning.

Answer: The spears will have the same horizontal force on them because the horizontal force is zero for both cases. There is no direct relationship between force and kinetic energy since force is proportional to acceleration, not to speed.

B4-SCT24: SKATERS PUSHING OFF EACH OTHER—FORCE

Two skaters—a small girl and a large boy—are initially standing face-to-face but then push off each other. After they are no longer touching, the girl has more kinetic energy than the boy. Three physics students make the following contentions about the forces the boy and girl exerted on each other:

Arianna: “I think the boy pushed harder on the girl because he is bigger, so she ended up with more kinetic energy than he did.”

Boris: “I disagree. They pushed equally hard on each other, but the girl moved farther while they were pushing on each other, so she ended up with more kinetic energy.”

Carmen: “I think the girl had to push harder to get the boy moving since he is bigger, but that caused her to accelerate more as she recoiled.”

With which, if any, of these students do you agree?

Arianna _____ Boris _____ Carmen _____ None of them _____

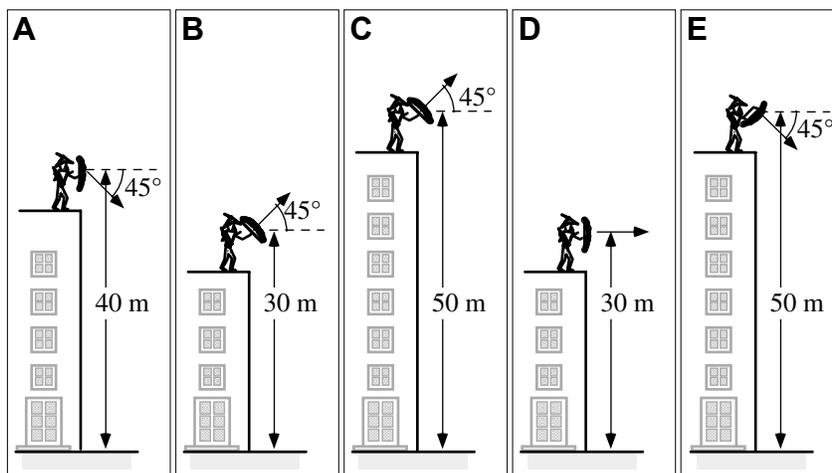
Explain your reasoning.

Answer: Boris is correct.

Newton’s Third Law requires that they exert forces of equal magnitude on each other and they are in contact for the same time. Equal force on the smaller mass of the girl will give her a larger acceleration. The larger acceleration for the same time means that she moves farther. Equal force applied through a larger distance means more work was done on her and so she ends up with more kinetic energy.

B4-RT25: ARROWS SHOT FROM BUILDINGS—FINAL SPEED

In each case below, an arrow has been shot from the top of a building either up at a 45° angle, straight out horizontally, or down at a 45° angle. All arrows are identical and are shot at the same speed, and the heights of the buildings and the direction the arrows are shot are given. Ignore air resistance.



Rank the speed of the arrows just before they hit the ground below.

					OR			
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

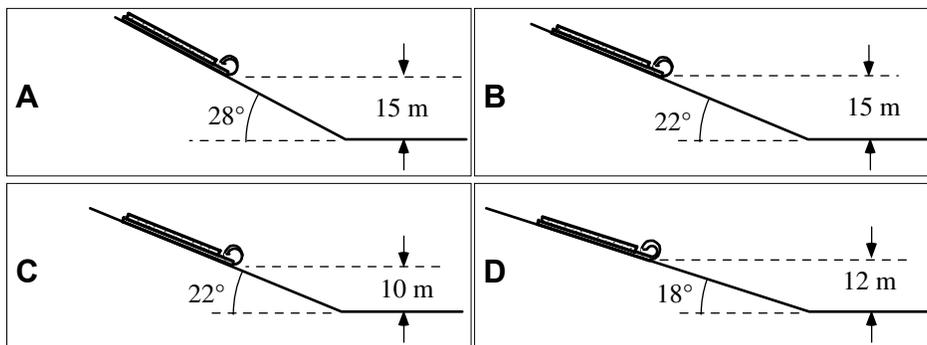
Explain your reasoning.

Answer: C = E > A > B = D.

This is an application of conservation of energy. All have the same kinetic energy at the start because they all are fired at the same speed. All arrows have zero gravitational potential energy at end of their flight, so those with greatest gravitational potential energy at start will have greatest kinetic energy and speed at bottom.

B4-RT26: TOBOGGANS GOING DOWN SLIPPERY HILLS—SPEED AT BOTTOM

In each case below, a toboggan starts from rest and slides without friction down a snowy hill. The toboggans are all identical, and the starting heights (vertical distance above the flat bottom of the incline) and angles of the hills are given.



Rank the speed of the toboggans at the bottom of the incline.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

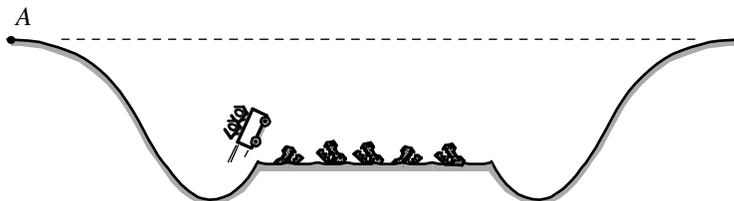
Explain your reasoning.

Answer: A = B > D > C

The speed depends on the starting height only. The initial gravitational potential energy of the toboggan will be proportional to the starting height, and without friction, all of this potential energy will be converted into kinetic energy at the bottom.

B4-CT27: ROLLER COASTER RIDE OVER LAGOON—MAXIMUM HEIGHT

For extra excitement, a new roller coaster ride is designed to launch the riders over an alligator-infested lagoon. The frictionless coaster starts at rest at point A. The coaster lands on a ramp on the other side of the lagoon.



After it is airborne, will the maximum height of the coaster be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the height at point A? _____

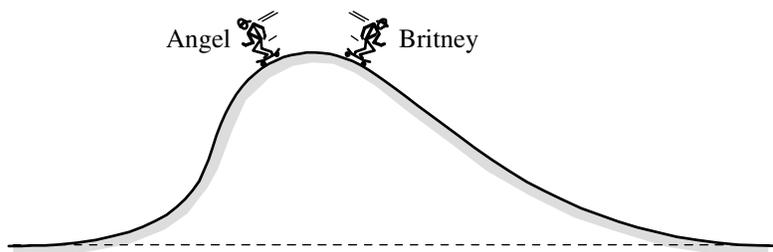
Explain your reasoning.

Answer: Less than.

All of the energy at point A is gravitational potential energy. At the highest point after launch the coaster will still be traveling horizontally, and will therefore have translational kinetic energy as well as gravitational potential energy. Since this final energy must equal the initial energy, the final gravitational potential energy must be less than the gravitational potential energy at point A. The coaster's maximum height will be less than the height at point A.

B4-CT28: SKATEBOARDERS ON A HILL—TIME, SPEED, KINETIC ENERGY, AND WORK

Starting from rest, Angel and Britney skateboard down a hill as shown. Angel rides down the steep side while Britney rides down the shallow side. Angel has more mass than Britney. Assume that friction and air resistance are negligible.



(a) Is the speed at the bottom of the hill (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

Answer-(iii) Same for both. Both skateboarders lose the same amount of height as they travel down the hill, and their change in potential energy (strictly speaking, the change in potential energy of the skateboarder-earth system) is equal to their gains in kinetic energy. Both kinetic and potential energy terms are proportional to the mass, so it doesn't matter that the skateboarders have different masses.

(b) Is the time it takes to get to the bottom of the hill (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

Answer-(ii) Greater for Britney. Both start from rest, and Angel, who will have the greater acceleration, also has a shorter path.

(c) Is the work done by the gravitational force on the skateboarder (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

Answer-(i) Greater for Angel. If the two skateboarders had the same mass, then the work done by the gravitational force would be the same for both. (Work depends only on displacement in direction of force, and the vertical displacement is the same for the two skateboarders). But since the gravitational force is proportional to the mass, this force is greater on Angel, and more work will be done on her by the gravitational force.

(d) Is the work done by the normal force on the skateboarder (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

Answer-(iii) Same for both. The displacement for each skateboarder at all points on the hill is parallel to the surface of the hill, and the normal force at all points is perpendicular to the hill, so the angle between the normal force and the displacement is 90° . Since work depends on the dot product of the force and displacement vectors, the work done by the normal force is zero for both skater

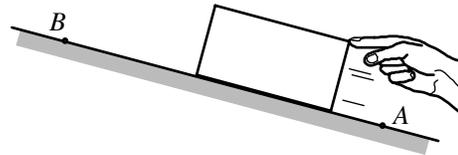
(e) Is the kinetic energy at the bottom of the hill (i) *greater* for Angel, (ii) *greater* for Britney, or (iii) *the same* for both skateboarders? _____

Explain your reasoning.

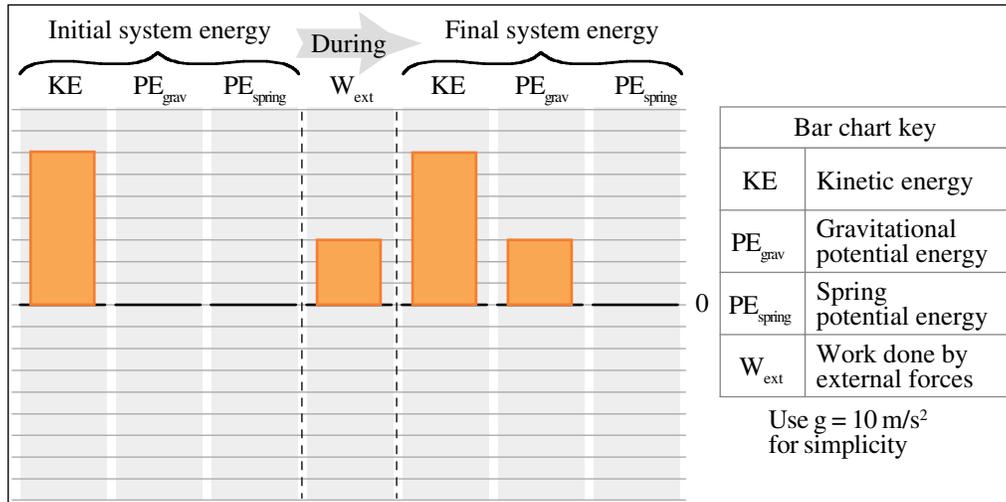
Answer: (i) Greater for Angel. They have the same speed, but Angel has a larger mass.

B4-BCT29: BLOCK PUSHED ON SMOOTH RAMP—ENERGY BAR CHART

A block is pushed so that it moves up a smooth (frictionless) ramp at constant speed from A to B.



Complete the energy bar chart for the earth-block system as the block moves from point A to B. Put the zero point for the gravitational potential energy at A.

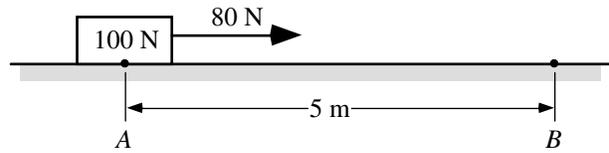


Explain your reasoning.

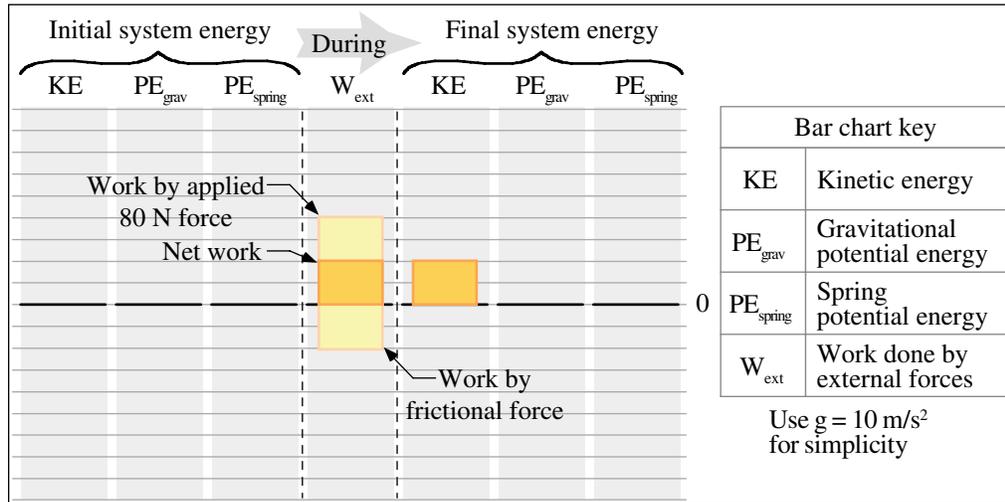
Answer: Since the block is moving at constant speed, there is no change in the kinetic energy. The push on the block has a component in the same direction as the displacement from A to B, so positive work is done on the block from A to B. Since the block is higher at B than at A, there is an increase in gravitational potential energy for the block-earth system.

B4-BCT31: BOX PULLED ON ROUGH SURFACE—ENERGY BAR CHART

A 100-N box is initially at rest on a rough, horizontal surface where the friction force is 40 N. A student applies a horizontal force of 80 N to the right on the box as shown. The box starts at rest at point A.



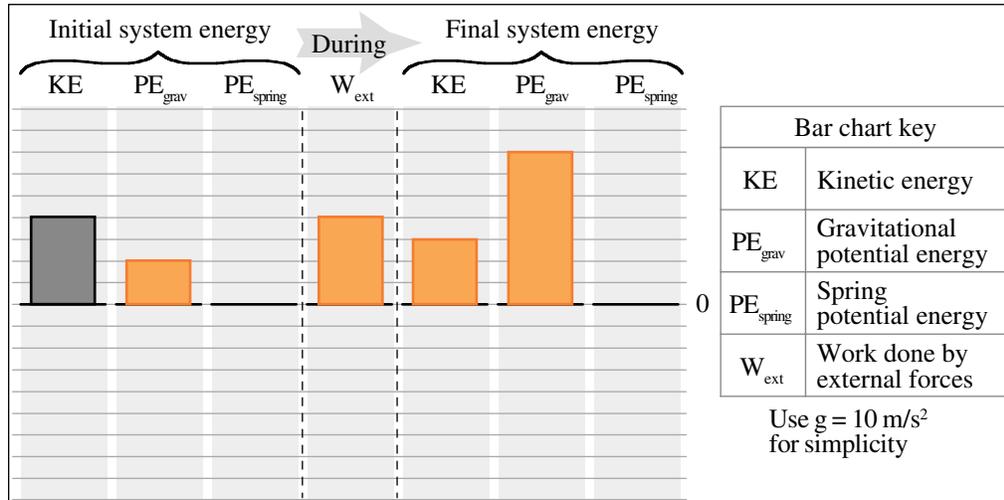
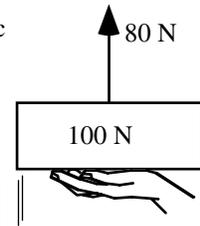
Complete the energy bar chart for the earth-box system before and after the box has moved a horizontal distance of 5.0 m. Put the zero point for the gravitational potential energy at the surface.



B4-BCT32: LIFTED BOX MOVING UPWARD I—ENERGY BAR CHART

A 100-N box is initially 0.40 m above the surface of a table and is moving upward with a kinetic energy of 80 J. A man is applying a constant upward force of 80 N with his hand to the box.

Complete the energy bar chart for the earth-box system before and after the box has moved upward a distance of 1.0 m. Put the zero point for the gravitational potential energy at the surface of the table.



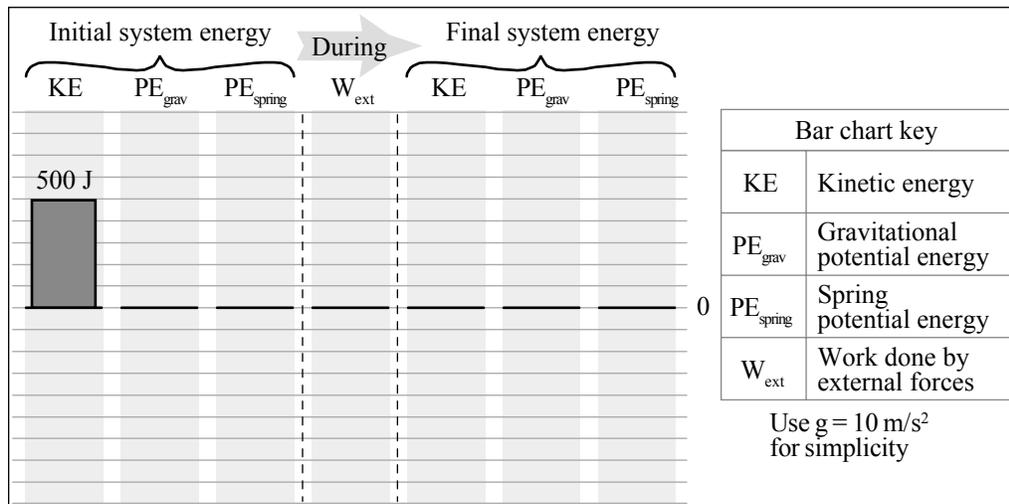
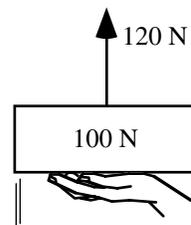
Explain your reasoning.

Answer: The initial kinetic energy is 80J, which corresponds to a bar 4 units high, one unit of height on the bar chart is 20J. The initial gravitational potential energy is $(100\text{N})(0.4\text{m}) = 40\text{J}$. The final gravitational potential energy is $(100\text{N})(1.4\text{m}) = 140\text{J}$. The 80 N force is applied in the same direction as the motion of the box, so it does positive work, equal to $(80\text{N})(1\text{m}) = 80\text{J}$. The total initial energy of the system was 120J, and 80J of work was done on the system as the box moved, so the total final energy of the system is 200J. Since 140J of this is gravitational potential energy, the final kinetic energy of the system must be 60J.

B4-BCT34: LIFTED BOX MOVING UPWARD II—ENERGY BAR CHART II

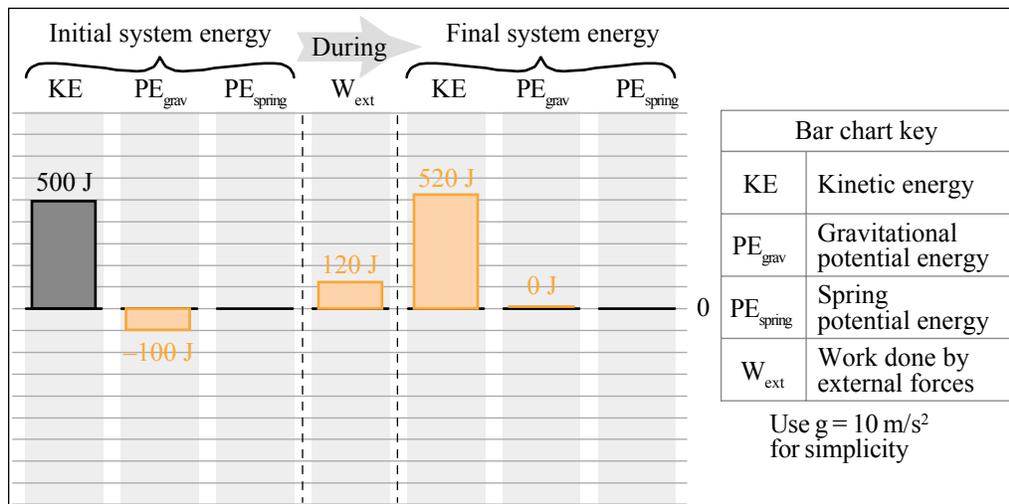
A 100-N box is initially 1.0 m above the ground while moving upward at 10 m/s. A student starts applying a vertical force of 120 N upward with her hand at this point.

Complete the energy bar chart for the earth-box system before and after the box has moved upward a distance of 1.0 m. Put the zero point for the gravitational potential energy at the final location at 2.0 m above of ground.



Explain your reasoning.

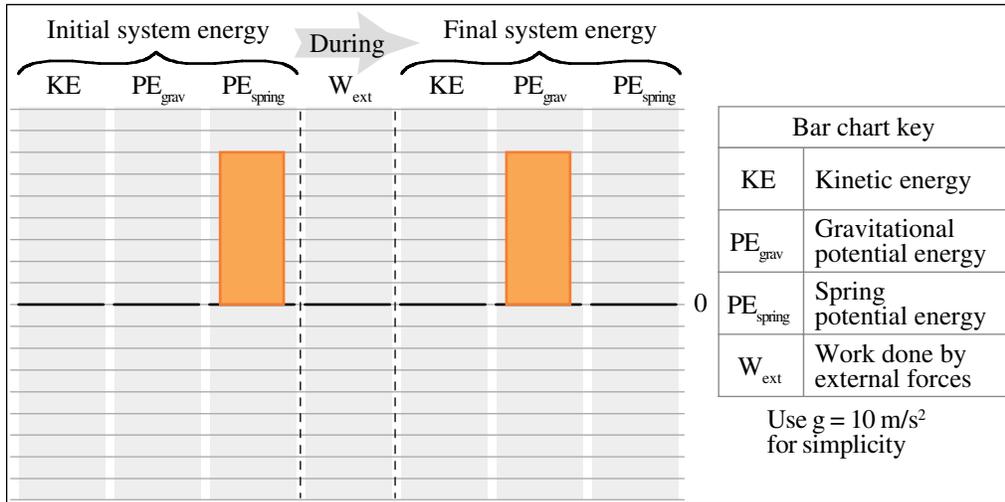
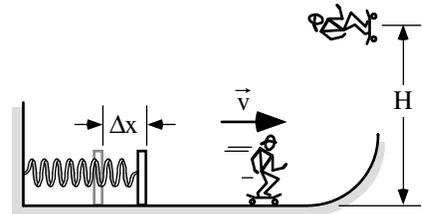
Answer: The box has 500 J of kinetic energy initially but now the gravitational potential energy of the earth-box system is a negative 100 J because the box starts below the gravitational potential energy zero level. The student again puts 120 J of energy into the system by working on it, so the total final energy of the system is 520 J. All of the final energy is kinetic energy since the box ends at the zero level for gravitational potential energy.



B4-BCT38: SKATEBOARDER LAUNCHED BY A SPRING II—ENERGY BAR CHART

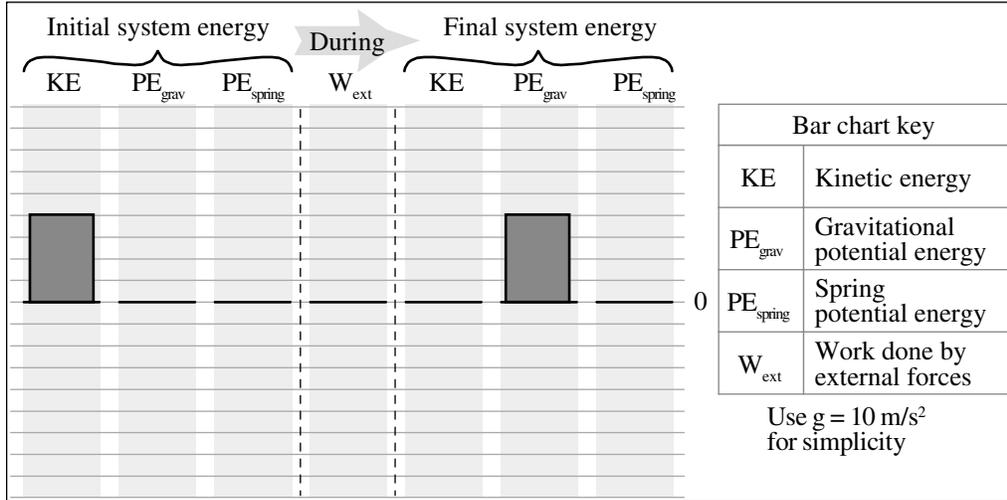
A performer on a skateboard is launched by a spring initially compressed a distance Δx as shown. His speed on the horizontal portion of the ramp is v , and he rises to a height H after he leaves the ramp. Ignore friction effects.

Draw an energy bar chart for the earth- skateboarder-spring system as he goes from the compressed spring position at rest to when he reaches the height H . Put the zero point for the gravitational potential energy at the initial height of the performer before launching.



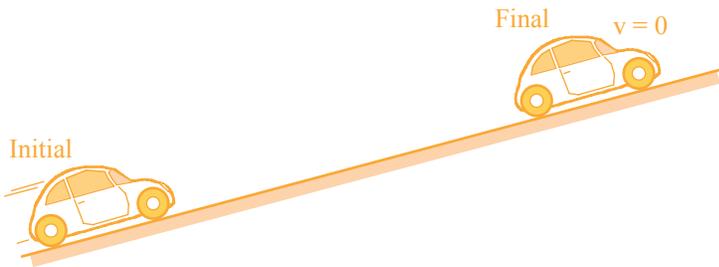
B4-WBT39: ENERGY BAR CHART I—PHYSICAL SITUATION

Describe a physical situation and a system to which this energy bar chart could apply.



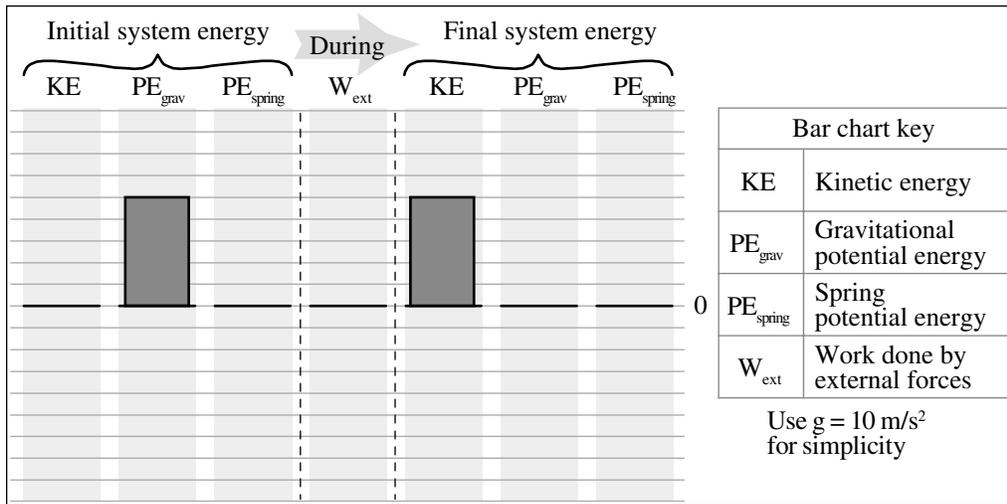
Explain your reasoning.

Answer: The object has some initial kinetic energy that is converted into gravitational potential energy as the object slows to a stop. The height of the object relative to the zero level for gravitational energy increases. Need to state that there are many other possibilities, and that the car here is coasting to rest. Also need to be clear that the system includes the earth.



B4-WBT40: ENERGY BAR CHART II—PHYSICAL SITUATION

Describe a physical situation and a system to which this energy bar chart could apply.



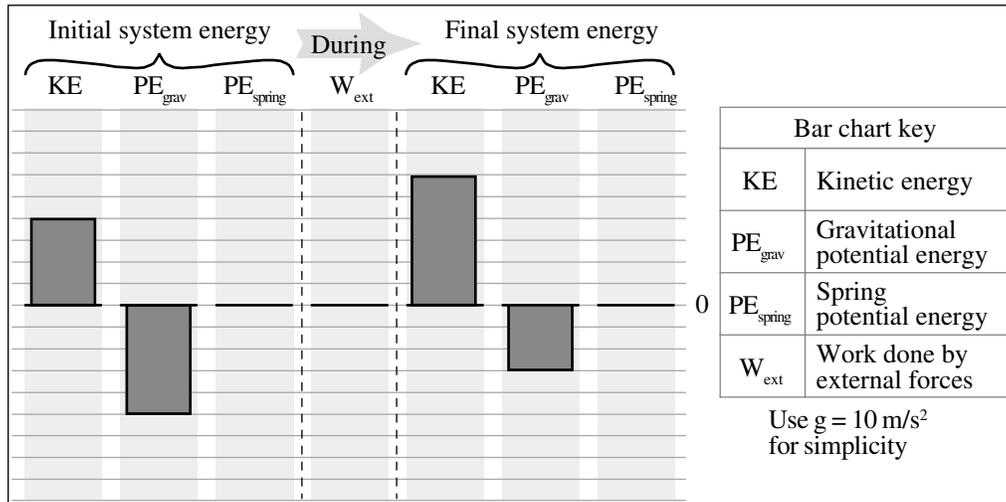
Explain your reasoning.

Answer: This is the opposite case of the previous situation. The object starts out above the gravitational potential energy zero and moves to the zero level increasing kinetic energy throughout.



B4-WWT41: SLIDING BOX—ENERGY BAR CHART

Shown is an energy bar chart drawn by a student.

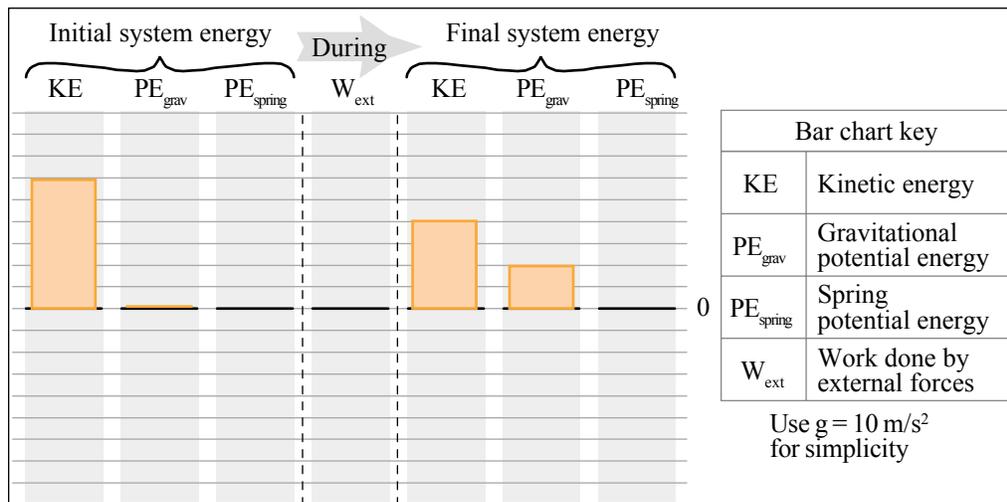


A student who drew this chart says:

“This chart is for a moving box sliding up a smooth slope from a lower point to a higher one. *The zero point for the gravitational potential energy is set at the ground level.*”

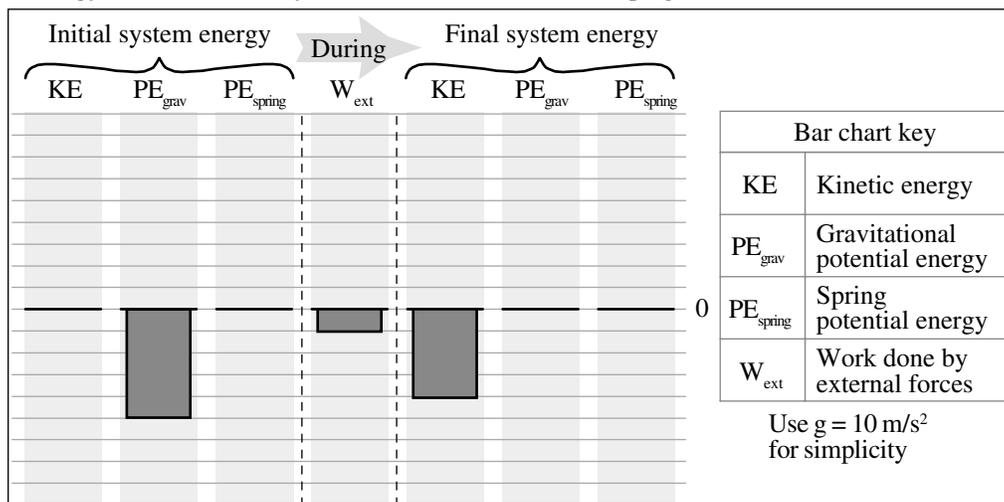
What, if anything, is wrong with this chart? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student’s statement and the bar chart are not consistent. The bar chart should look like the one below since the box, which we will assume starts at the bottom of the slope where the gravitational potential energy is zero, initially has kinetic energy some of which is going to be converted into gravitational potential energy as the box moves up the incline.



B4-WWT42: BOX ON SLOPING HILL—ENERGY BAR CHART

Shown is an energy bar chart drawn by a student about a box on a sloping hill.

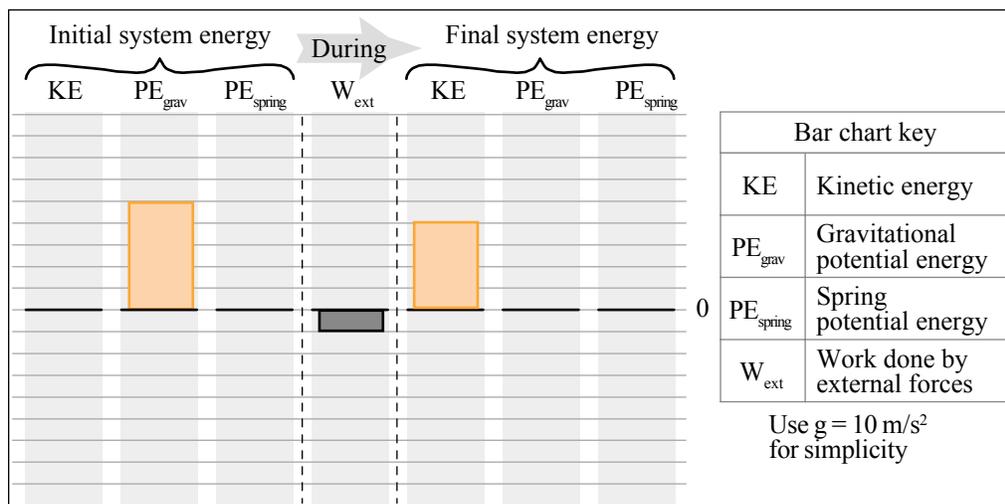


A second student says:

“No, this is not correct since the work done must be positive.”

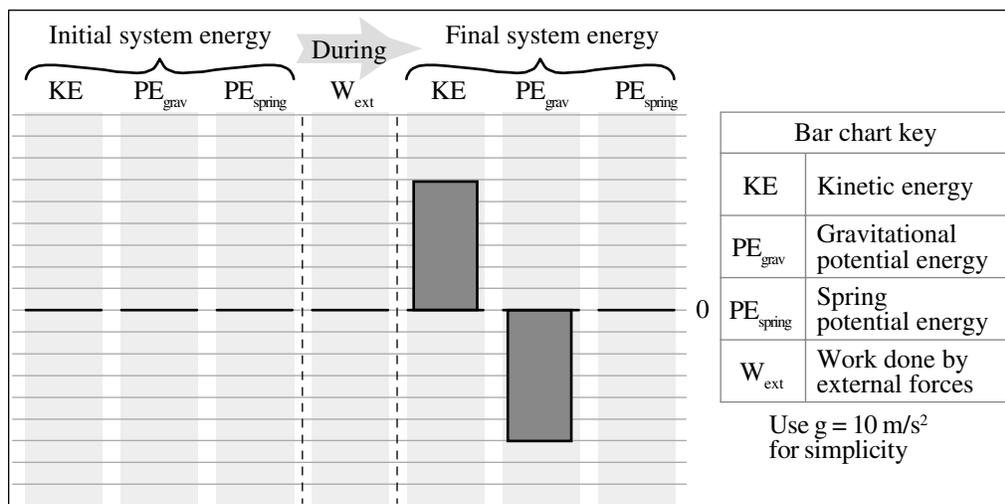
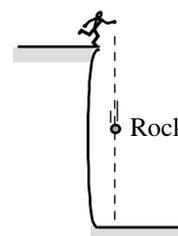
What, if anything, is wrong with this chart? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: Both the bar chart drawn by the first student and the second student’s statement are wrong. The problem with the bar chart is that the gravitational potential energy and the kinetic energy should both be positive. The problem with the second student’s statement is that kinetic energy can never be negative, which then means the initial gravitational potential energy needs to be positive also and the energy exchange via working is correct as negative. This is shown in the appropriate bar chart below.

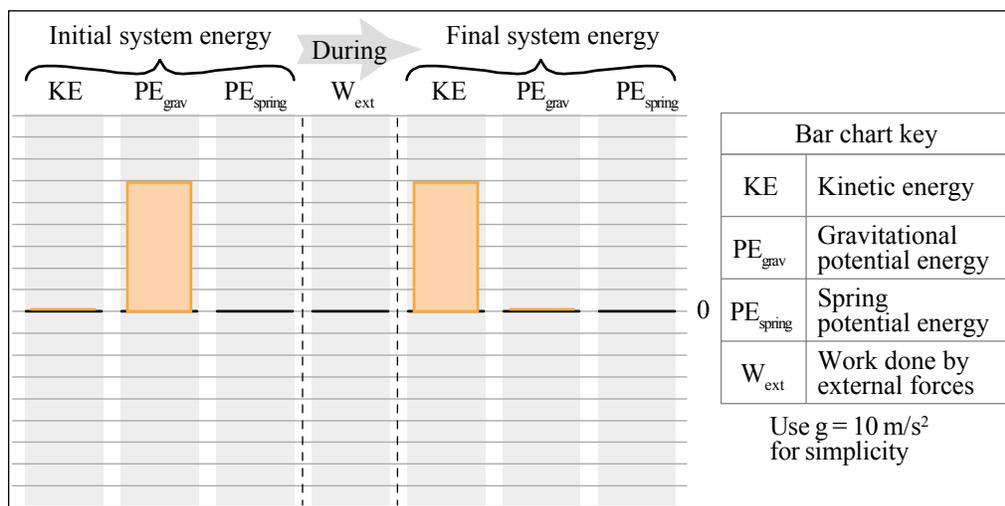


B4-QRT43: DROPPED ROCK—ENERGY BAR CHART

A rock is dropped by a student from the top of a cliff and falls straight to the ground below. He constructs an energy bar chart shown below using a coordinate system in which the positive vertical direction is up and the origin of the coordinate system is the release point of the rock which is also selected as the zero point for the gravitational potentials energy.



Draw a new energy bar chart for this event but use the ground as the zero point for the potential gravitational energy.

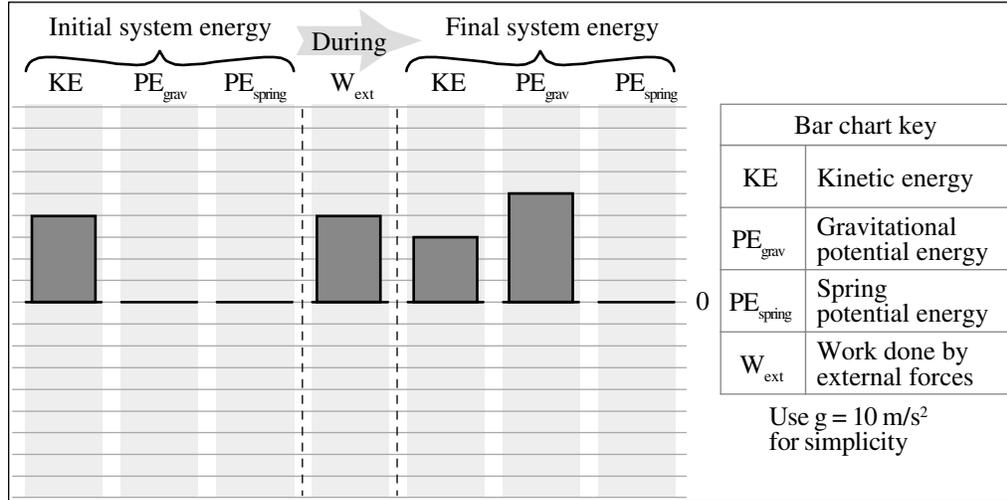


Explain your reasoning.

Answer: Since the ground is now the gravitational potential energy zero the rock initially had positive gravitational potential energy, all of which is converted to kinetic energy just before the rock hits the ground.

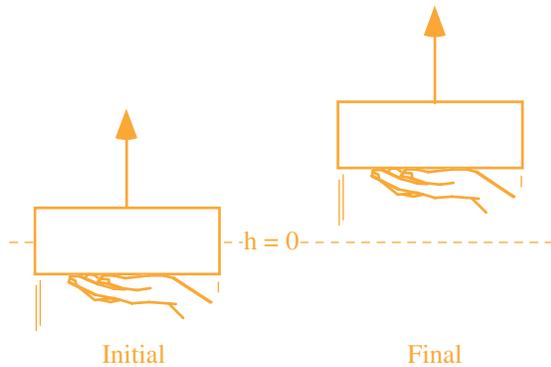
B4-WBT44: ENERGY BAR CHART—PHYSICAL SITUATION

Describe a physical situation and a system to which this energy bar chart could apply.



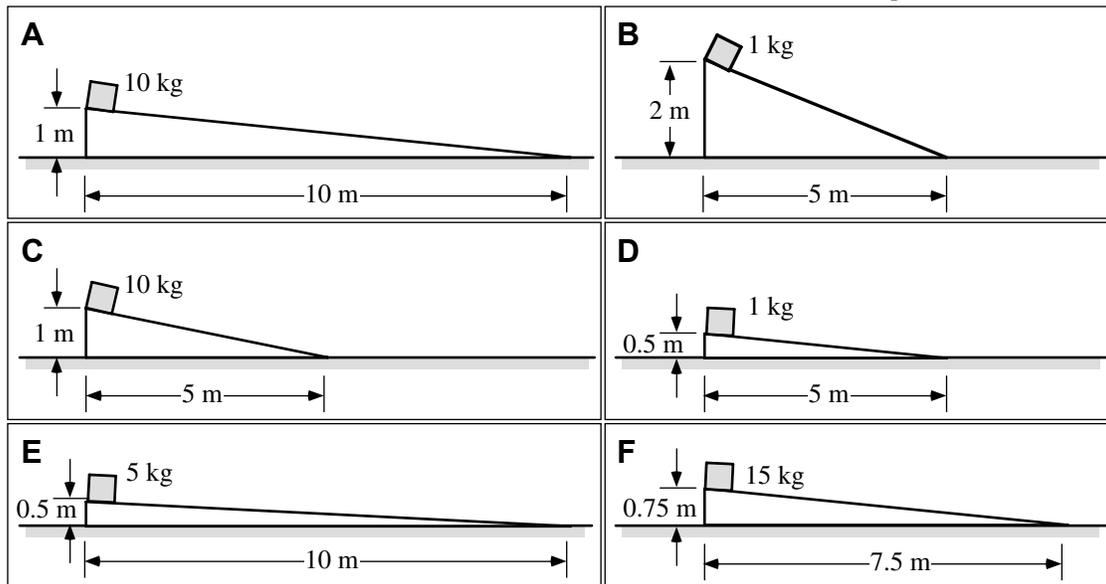
Explain your reasoning.

Answer: There is initial kinetic energy, and the final kinetic energy is smaller than the initial kinetic energy. So the system is slowing down. At the same time, the system starts with no gravitational potential energy and gains positive gravitational potential energy. Positive work is done by an external force on the system, so the object is being pushed or pulled in the direction of motion. One possibility is a system consisting of a block and the earth. The block is moving upward initially, and is being pushed by a force whose magnitude is less than the weight of the block. The system is the box and the Earth.



B4-RT45: SLIDING MASSES ON INCLINE—KINETIC ENERGY

Shown are blocks that slide down frictionless inclines. All masses start from rest at the top of the incline.



Rank the kinetic energy of the sliding masses the instant they reach the bottom of the incline.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>					
1	2	3	4	5	6		All	All	Cannot
Greatest					Least		the same	zero	determine

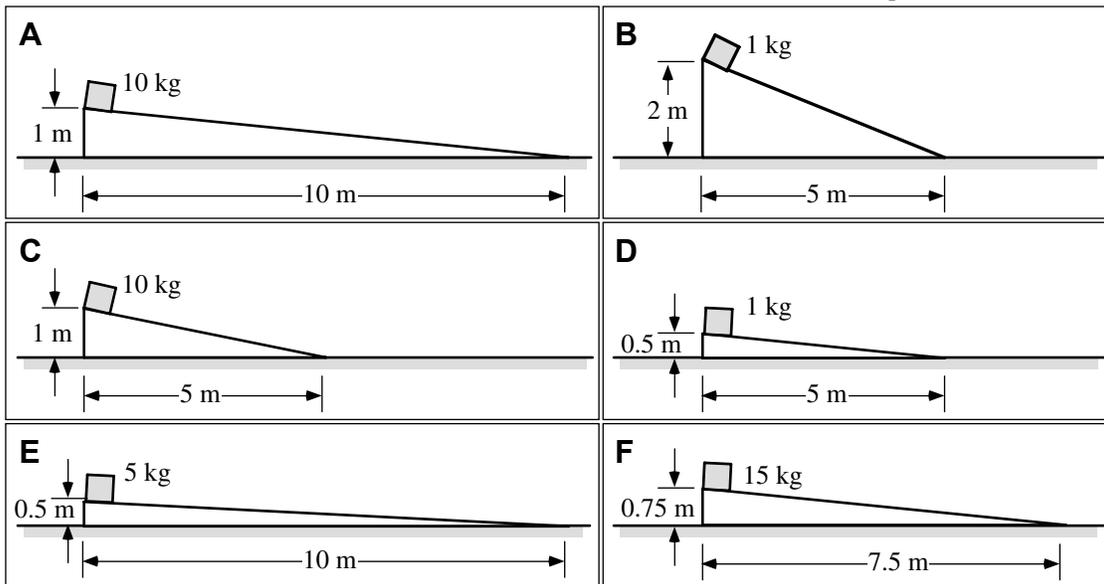
Explain your reasoning.

Answer: $F > A = C > B > D = E$.

Since the blocks all start from rest so they have zero initial kinetic energy, and they are sliding down frictionless surfaces, the initial gravitational potential energy, which depends on the height of the incline, is converted to the final kinetic energy. The initial gravitational potential energy is proportional to the product of the mass and the height above the horizontal surface, length of the incline is irrelevant.

B4-RT46: SLIDING MASSES ON INCLINE—CHANGE IN POTENTIAL ENERGY

Shown are blocks that slide down frictionless inclines. All masses start from rest at the top of the incline.



Rank the change in gravitational potential energy of the sliding masses from the top of the incline to the bottom of the incline.

<input style="width: 100%; height: 20px;" type="text"/>	OR	<input style="width: 100%; height: 20px;" type="text"/>	<input style="width: 100%; height: 20px;" type="text"/>	<input style="width: 100%; height: 20px;" type="text"/>					
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

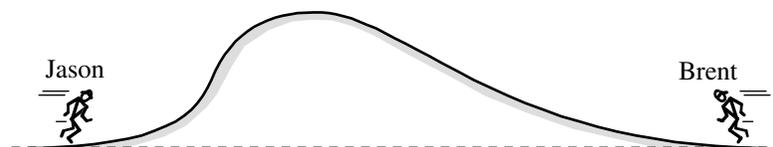
Explain your reasoning.

Answer: $F > A = C > B > D = E$.

Since the initial gravitational potential energy depends on the height of the incline and the mass of the block, which does not change as the block slides down the incline, the ranking is based on the product of the height and mass.

B4-CT47: RACE UP A HILL I—WORK AND POWER

Jason and Brent race up a hill that is 30 m high. Jason takes a path that is 60 m while Brent uses a longer path that is 100 m long. It takes Jason 40 seconds, while Brent runs up his path in a shorter time of 30 seconds. They both start from rest at the same height and stop at the top. Also, they have the same weight.



(a) Is the work that Jason does in going up the hill (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work that Brent does in going up the hill? _____

Explain your reasoning.

Answer: (iii) the same as since the height and weight are the same.

The change in gravitational potential energy is the same— mgh —for both so that is the work they do.

(b) Is the power generated by Jason in going up the hill (i) *greater than*, (ii) *less than*, or (iii) *the same as* the power generated by Brent in going up the hill? _____

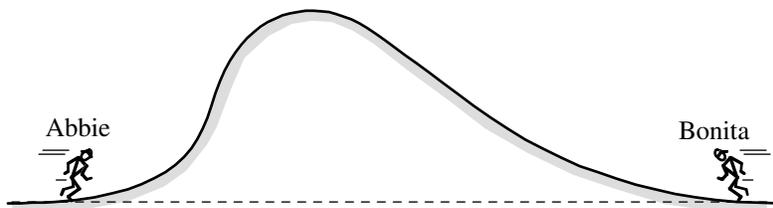
Explain your reasoning.

Answer: (ii) less than since the time for Jason is longer (40 s).

Power is the change in energy per unit time. Since the energy changes are equal, but the time is longer for Jason he generates less power.

B4-CT48: RACE UP A HILL II—WORK AND POWER

Abbie and Bonita decide to race up a hill that is 30 m high. Abbie takes a path that is 60 m long while Bonita uses a path that is 100 m long. It takes Abbie 40 seconds because her route is steep, while Bonita runs up her path in 30 seconds. They both start from rest at the same height and stop at the top. Abbie has a weight of 700 N, and Bonita has a weight of 500 N.



(a) Is the work that Abbie does in going up the hill (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work that Bonita does in going up the hill? _____

Explain your reasoning.

Answer: (i) greater than, since the work done is equal to the gain in gravitational potential energy, which is the weight times the height, and both went up the same height, but Abbie weighs more than Bonita.

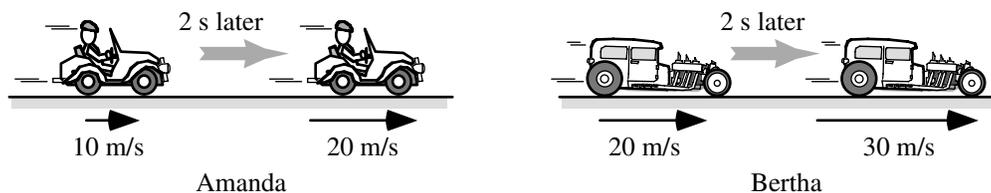
(b) Is the power generated by Abbie in going up the hill *greater than*, *less than*, or *the same as* the power generated by Bonita in going up the hill? _____

Explain your reasoning.

Answer: (i) greater than, since the power is the rate that work is done so it will be the work/time. For Abbie it is (700 N)(30 M)/40 s while for Bonita, it is (500 N)(30 m)/30 s.

B4-CT49: CAR RACE—WORK AND POWER

Amanda and Bertha are in a car race. Their cars have the same mass. At one point in the race, they both change their speeds by 10 m/s in 2 seconds. Ignore air friction.



(a) Is the work that Amanda's car does while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work that Bertha's car does while speeding up? _____

Explain your reasoning.

Answer: (ii) less than, since the work done is equal to the change in kinetic energy, which will be proportional to the change in the square of the velocity. For Amanda, it is $(20 \text{ m/s})^2 - (10 \text{ m/s})^2 = 400 \text{ m}^2/\text{s}^2 - 100 \text{ m}^2/\text{s}^2 = 300 \text{ m}^2/\text{s}^2$ and for Bertha, it is $(30 \text{ m/s})^2 - (20 \text{ m/s})^2 = 900 \text{ m}^2/\text{s}^2 - 400 \text{ m}^2/\text{s}^2 = 500 \text{ m}^2/\text{s}^2$.

(b) Is the power generated by Amanda's car while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the power generated by Bertha's car while speeding up? _____

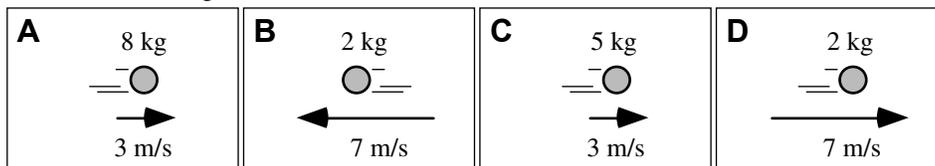
Explain your reasoning.

Answer: (ii) less than, since the power is the rate work is done, so it is the work done divided by the time it takes. Since the time is the same, and the work done is less for Amanda's car, the power generated by Amanda's car will be less.

B5 MOMENTUM AND IMPULSE

B5-RT01: MOVING BALL I—MOMENTUM AND KINETIC ENERGY

In the figures below, balls are traveling in different directions. The balls have the same size and shape, but they have different masses and are traveling at different velocities as shown.



(a) Rank the magnitude of the momentum of the balls.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: $A > C > B = D$.

*Based on magnitude of the momentum = mass*instantaneous speed.*

(b) Rank the kinetic energy of the balls.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

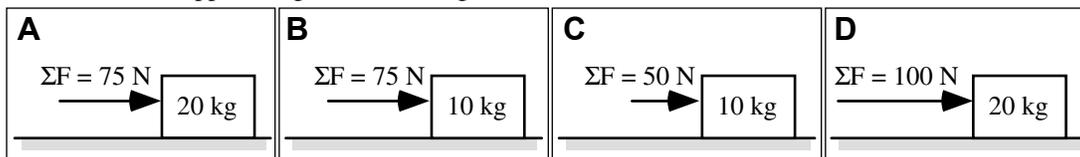
Explain your reasoning.

Answer: $B = D > A > C$.

*Based on definition of kinetic energy one-half the mass*velocity².*

B5-RT02: FORCE PUSHING BOX I—CHANGE IN MOMENTUM

Identical boxes that are filled with different objects are initially at rest. A horizontal force is applied for 10 seconds, and the boxes move across the floor. The mass of the box with its contents and the *net* force acting on the box while the horizontal force are applied is given in each figure.



Rank the magnitude of the change in momentum during a 10-second interval for each box.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

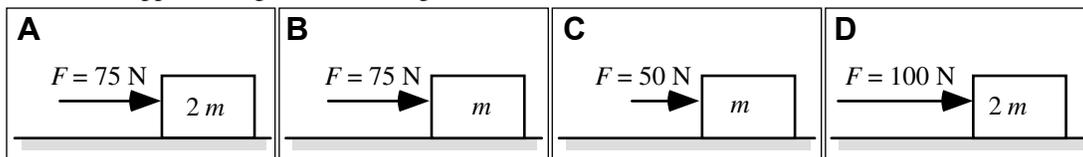
Explain your reasoning.

Answer: $D > A = B > C$.

The time interval is the same for all four cases, so the magnitudes of the momentum changes, which are equal to the impulses applied to the boxes, will be proportional to the net forces acting.

B5-RT03: FORCE PUSHING BOX II—IMPULSE

Identical boxes that are filled with different amounts of sand are initially at rest. A horizontal force is applied, and the boxes move across the floor. The mass of the box with its contents and the *net* force acting on the box while the horizontal force is applied are given in each figure.



Rank the magnitude of the impulse on each box for a 2-second time interval.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

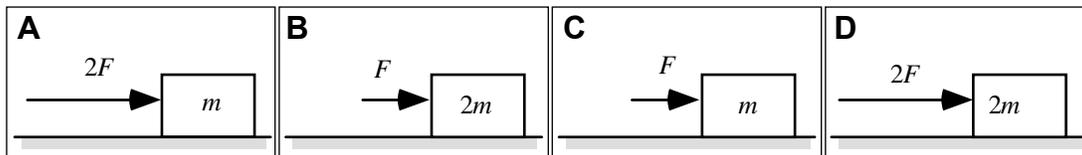
Explain your reasoning.

Answer: A = D > B = C.

Impulse is defined as $F \cdot t$, so here we can rank on F since the time is the same for all four.

B5-RT04: FORCE PUSHING BOX III—CHANGE IN MOMENTUM

Identical boxes that are filled with different amounts of sand are initially at rest. A horizontal force is applied, and the boxes move across the floor. The mass of the box with its contents and the *net* force acting on the box while the horizontal force is applied are given in each figure.



Rank the magnitude of the change in momentum for each box for the same time interval.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

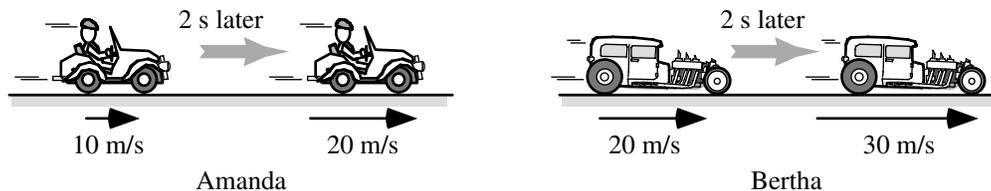
Explain your reasoning.

Answer: A = D > B = C.

Since change in momentum related to impulse = $F \cdot t$, so we can rank on F since the time is the same for all four cases.

B5-QRT05: AMANDA AND BERTHA'S CAR RACE—WORK AND IMPULSE

Amanda and Bertha are driving cars in a race. Their two cars, including Amanda and Bertha, have the same mass. At one point in the race, they both change their speeds by 10 m/s in 2 seconds. Ignore air friction.



(a) Is the work done on Amanda's car while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done on Bertha's car while speeding up? _____

Explain your reasoning.

Answer: (ii) less than.

Since the energy added to the car goes into its kinetic energy the ranking is proportional to the change in velocity squared (400-100 as compared to 900-400)

(b) Is the impulse on Amanda's car while speeding up (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done on Bertha's car does while speeding up? _____

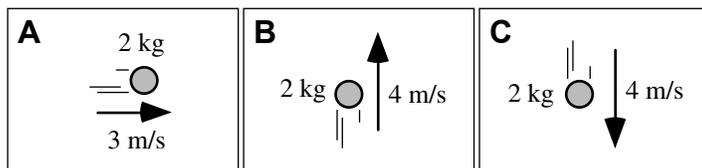
Explain your reasoning.

Answer: (iii) same as.

Since the impulse is proportional to the change in momentum or the velocity (20-10 as compared to 30-20).

B5-RT06: MOVING BALL II—MOMENTUM AND KINETIC ENERGY

In the figures below, balls are traveling in different directions. The balls have the same size, mass and shape, but they are traveling with different velocities as shown.



(a) Rank the magnitude of the momentum of the balls.

<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3		All	All	Cannot
Greatest		Least		the same	zero	determine

Explain your reasoning.

Answer: B = C > A.

*Ranked on velocity based on magnitude of the momentum = mass*velocity which is proportional to velocity only since the mass is the same.*

(b) Rank the kinetic energy of the balls.

<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3		All	All	Cannot
Greatest		Least		the same	zero	determine

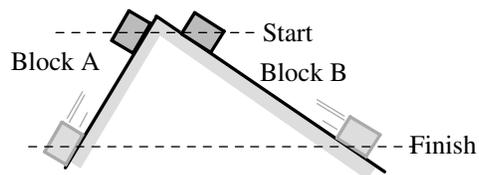
Explain your reasoning.

Answer: B = C > A.

*Ranked on velocity based on kinetic energy is proportional to mass*velocity² which is proportional to velocity only since the mass is the same.*

B5-QRT07: BLOCKS SLIDING DOWN FRICTIONLESS RAMPS—WORK AND MOMENTUM

Two blocks are released from rest at the same height. Block A slides down a steeper ramp than Block B. Both ramps are frictionless. The blocks reach the same final height indicated by the lower dashed line. Block B weighs more than Block A.



(a) Is the work done by the gravitational force on Block A (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done by the gravitational force on Block B? _____
Explain your reasoning.

Answer: (ii) less than.

Since Block A has the smaller mass/weight and they fall through the same height.

(b) Is the speed of Block A (i) *greater than*, (ii) *less than*, or (iii) *the same as* the speed of Block B? _____
Explain your reasoning.

Answer: (iii) same.

Since energy is conserved and mass cancels in $mgh=mv^2/2$

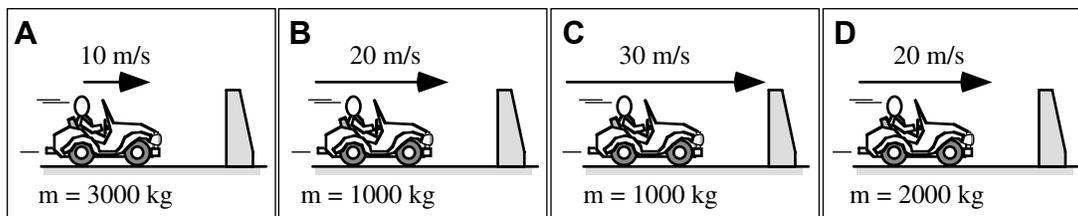
(c) Is the momentum of Block A (i) *greater than*, (ii) *less than*, or (iii) *the same as* the momentum of Block B? _____
Explain your reasoning.

Answer: (ii) less than.

Since Block A has the smaller mass/weight with the same speed as B.

B5-RT08: CARS STOPPED BY CONSTANT FORCE BARRIERS—STOPPING TIME

Cars moving along horizontal roads are about to be stopped when they hit a protective barrier. All of the cars are the same size and shape, but they are moving at different speeds and have different masses. The barriers are all identical and exert the same constant force.



Rank the time that it takes to stop the cars as the barriers apply the same constant force.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

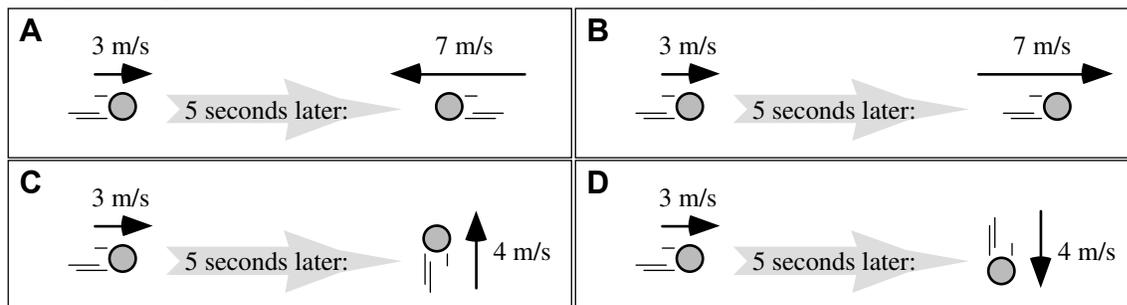
Explain your reasoning.

Answer: $D > A = C > B$.

Since the same force is acting on all cars and we are asked about the time interval to bring the cars to rest, the physical quantity involved is the momentum. The barriers are going to exert an impulse on the cars bringing them to rest and that impulse will be equal to the change in momentum for the cars. So the ranking is based on the product of the mass and velocity.

B5-QRT09: OBJECT CHANGING VELOCITY—DIRECTION OF THE IMPULSE

An object changes its velocity as forces act on it for 5 seconds in various ways shown below.



For the question below, use the directions indicated by the arrows in the direction rosette, or use **J** for no direction, **K** for into the page, or **L** for out of the page.

(a) Identify the closest directional match for the direction of the impulse on the ball for these cases.

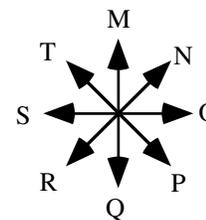
Explain your reasoning.

*Answer: A is S, B is O,
C is T, D is R.*

Impulse is the change in momentum

so we need to take the final momentum minus the initial momentum taking account of the fact that momentum is a vector quantity.

A	B
C	D



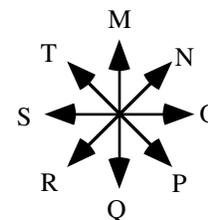
(b) Identify the closest directional match for the direction of the change in the momentum for the ball for these cases.

Explain your reasoning.

*Answer: A is S, B is O,
C is T, D is R.*

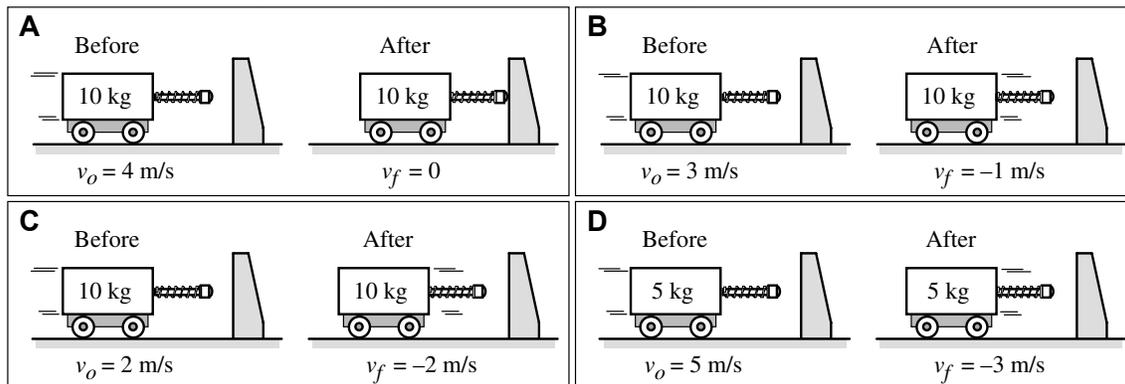
Both parts (a) and (b) are the same since the Impulse = Change in momentum

A	B
C	D



B5-RT10: BOUNCING CART I—CHANGE IN MOMENTUM

Carts with spring plungers run into fixed barriers. The carts are identical but are carrying different loads and so have different masses. The velocity of the cart just before and just after impact is given.



Rank the magnitude of the change in momentum of these carts.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

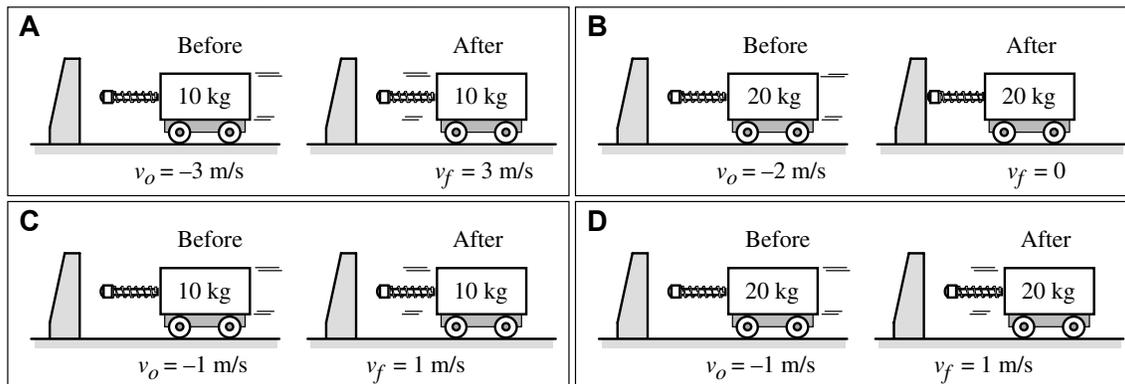
Explain your reasoning.

Answer: All have the same change in momentum, 40 kgm/s to the left.

The change in momentum is the final momentum minus the initial momentum, but in calculating this we have to keep in mind that momentum is a vector quantity. That means our calculations have to use the signs of the velocity, so for example, the change in momentum of case B (with positive directions to the right) is $-10 \text{ (kg)(m)/s} - 30 \text{ (kg)(m)/s} = -40 \text{ (kg)(m)/s}$.

B5-RT11: BOUNCING CART II—CHANGE IN MOMENTUM

Carts with spring plungers run into fixed barriers. The carts are identical but are carrying different loads and so have different masses. The velocity of each cart just before and just after impact is given.



Rank the magnitude of the change in momentum of the carts.

1	2	3	4	OR	All	All	Cannot
Greatest			Least		the same	zero	determine

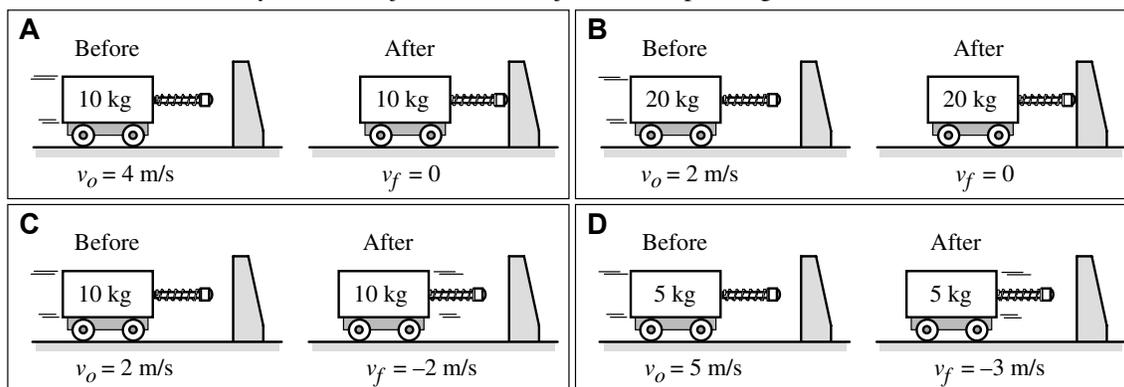
Explain your reasoning.

Answer: A > B = D > C.

The change in momentum is the final momentum minus the initial momentum, but in doing this we have to keep in mind that momentum is a vector quantity. That means our calculations have to use the signs of the velocity, so for example, the change in momentum of case B (with positive directions to the right) is $0 \text{ (kg)(m)/s} - (-40 \text{ (kg)(m)/s}) = 40 \text{ (kg)(m)/s}$. In all four cases we end up with a positive momentum change.

B5-QRT12: BOUNCING CART—DIRECTION OF THE CHANGE IN MOMENTUM

Carts with spring plungers run into fixed barriers. The carts are identical but are carrying different loads and so have different masses. The velocity of the cart just before and just after impact is given.



(a) Is the direction of the change in momentum in Case A to the left or to the right? If the change in momentum cannot be determined, state that explicitly. _____

Explain your reasoning.

Answer: Towards the left. The initial momentum is directed right and the final momentum is zero so the change had to be directed to the left.

(b) Is the direction of the change in momentum in Case B to the left or to the right? If the change in momentum cannot be determined, state that explicitly. _____

Explain your reasoning.

Answer: Towards the left. The initial momentum is directed right and its final momentum is zero so the change had to be directed to the left.

(c) Is the direction of the change in momentum in Case C to the left or to the right? If the change in momentum cannot be determined, state that explicitly. _____

Explain your reasoning.

Answer: Towards the left. The initial momentum is directed right and the final momentum is negative, which here means to the left, so the change had to be directed to the left.

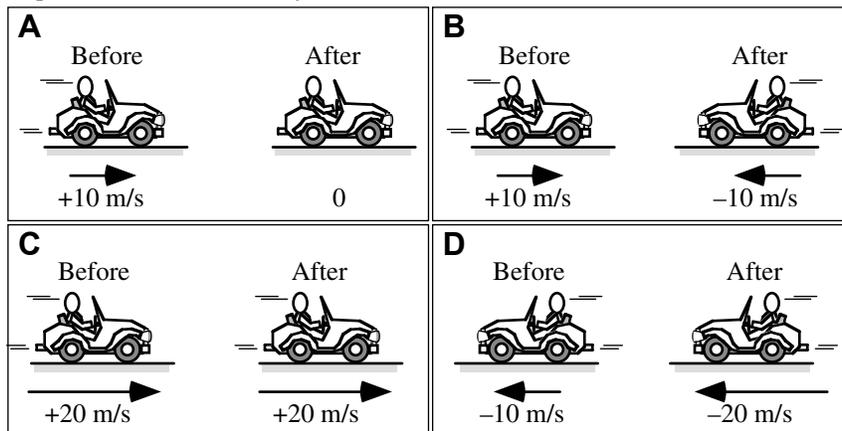
(d) Is the direction of the change in momentum in Case D to the left or to the right? If the change in momentum cannot be determined, state that explicitly. _____

Explain your reasoning.

Answer: Towards the left. The initial momentum is directed right and the final momentum is negative, which here means to the left, so the change had to be directed to the left.

B5-RT13: CARS—CHANGE IN MOMENTUM DURING A CHANGE OF VELOCITY

Before and after "snapshots" of a car's velocity are shown. All cars have the same mass.



Rank the magnitude of the change in momentum of the cars.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

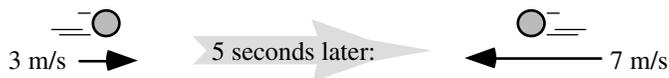
Explain your reasoning.

Answer: B > A = D > C.

Since the masses are all the same the magnitudes of the momenta changes will be equal to the difference in the velocities, keeping in mind that velocity is a vector quantity. For example, in A the change in velocity is $(0 - 10)m/s = -10 m/s$ and in D it is $(-20 - -10)m/s = -10 m/s$.

B5-SCT14: OBJECT CHANGING VELOCITY I—IMPULSE

A 2-kg object accelerates as a net external force is applied to it. During the 5-second interval that the force is applied, the object's velocity changes from 3 m/s to the right to 7 m/s to the left.



Several students discussing the impulse on this object state the following:

Andre: “The impulse is equal to the change in momentum, which is $(2 \text{ kg})(3 \text{ m/s} + 7 \text{ m/s}) = 20 \text{ kg}\cdot\text{m/s}$.”

Bela: “But the change in velocity is 4 m/s. We multiply by the mass to get the change in momentum, and also the impulse, which is 8 kg·m/s.”

Carleton: “The change in momentum of this object during these 5 seconds was 8 kg·m/s so the impulse applied to this object during these 5 seconds was 8/5 kg·m/s.”

Dylan: “The impulse is the force F times the time t , and since we don't know the force, we can't find the impulse for this situation.”

With which, if any, of these students do you agree?

Andre _____ Bela _____ Carleton _____ Dylan _____ None of them _____

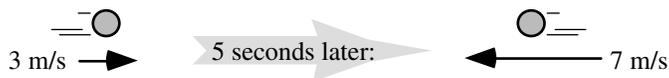
Explain your reasoning.

Answer: None of these students are correct.

The change in velocity is the final velocity minus the initial velocity, or 10 m/s leftward. So the change in momentum is 20 kg·m/s left. Andre has the correct magnitude but has forgotten to include the direction of this vector quantity and his calculation does not use the correct velocities.

B5-WWT15: OBJECT CHANGING VELOCITY II—IMPULSE

A 2-kg object accelerates as a net external force is applied to it. During the 5-second interval that the force is applied, the object's velocity changes from 3 m/s to the right to 7 m/s to the left.



A student states:

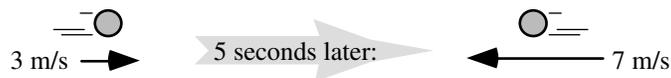
“The change in momentum of this object during these 5 seconds was 8 kg·m/s, so the impulse applied to this object during these 5 seconds was 8/5 kg·m/s.”

What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct all errors. If this statement is correct, explain why.

Answer: This statement is incorrect because (1) momentum is a vector so a direction should be specified for the change in momentum, (2) impulse = change in momentum so the time does not enter into the problem, and (3) the actual change in momentum (taking right as positive) is $(2\text{kg})(-7\text{m/s}) - (2\text{kg})(+3\text{m/s}) = -20 \text{ kg}\cdot\text{m/s}$, or 20 kg·m/s to the left.

B5-WWT16: OBJECT CHANGING VELOCITY III—IMPULSE

A 2-kg object accelerates as a net external force is applied to it. During the 5-second interval that the force is applied, the object's velocity changes from 3 m/s to the right to 7 m/s to the left.



A student states:

"The change in velocity for this 2 kg object was 4 m/s, so the change in momentum, and also the impulse, was 8 kg·m/s."

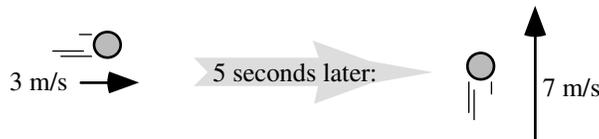
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: This statement is incorrect because momentum is a vector so the change in momentum (taking to the right as the positive direction) is equal to $2 \text{ kg} (-7 \text{ m/s} - (+3 \text{ m/s})) = -20 \text{ kg}\cdot\text{m/s}$, or $20 \text{ kg}\cdot\text{m/s}$ to the left.

B5-WWT17: OBJECT CHANGING VELOCITY IV—IMPULSE

A student proposes the following description for the impulse on a 2-kg object that changes direction and speed as shown:

“The object goes from moving at 3 m/s in the positive x-direction to 7 m/s in the positive y-direction in 5 seconds. So the impulse given to it is 8 kg·m/s, since the impulse equals the change in momentum. The 5 seconds does not enter into the calculation of this impulse.”

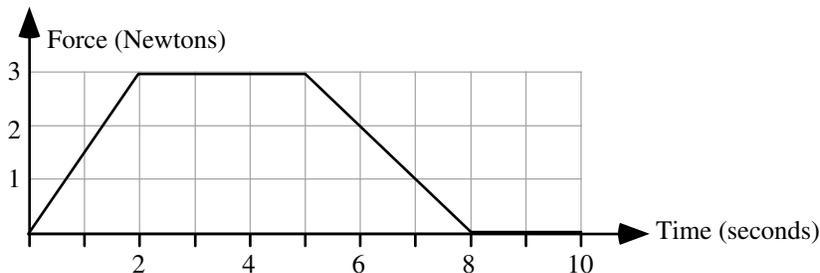


What, if anything, is wrong with this statement? If anything is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The 8 kg·m/s is incorrect since the impulse and the change in momentum are vector quantities and this description does not treat them as such. Using a coordinate axis with positive x to the right and positive y toward the top of the page, the final momentum of the object is zero in the x-direction, so the change in momentum in the x-direction is $-6 \text{ kg}\cdot\text{m/s}$. The initial momentum of the object in the y-direction is zero, so the change in momentum in the y-direction is $14 \text{ kg}\cdot\text{m/s}$. We can use the Pythagorean theorem to find the magnitude of the change in momentum, which is $15.2 \text{ kg}\cdot\text{m/s}$. The direction of the change in momentum is 23.2 degrees to the left of the positive-y axis.

B5-RT18: FORCE-TIME GRAPH I—IMPULSE APPLIED TO BOX

A 10-kg box, initially at rest, moves along a frictionless horizontal surface. A horizontal force to the right is applied to the box. The magnitude of the force changes as a function of time as shown.



Rank the impulse applied to the box by this force during each 2-second interval indicated below.

A. 0 to 2 s

B. 2 to 4 s

C. 4 to 6 s

D. 6 to 8 s

E. 8 to 10 s

					OR			
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

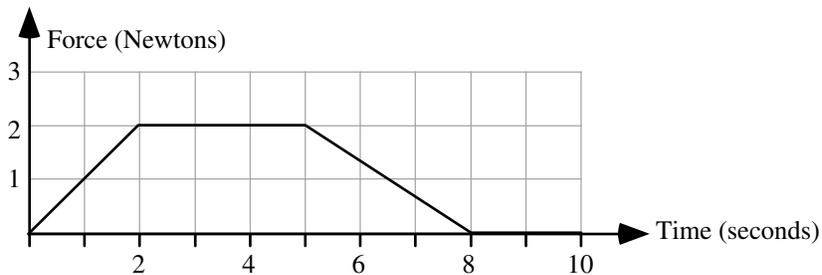
Explain your reasoning.

Answer: B > C > A > D > E.

The impulse for each time interval is equal to the area under the graph during that time interval. From zero to 2 seconds this is 2 kg m/s; from 2 to 4 seconds it is 4 kg m/s; from 4 to 6 seconds it is 3.67 kg m/s; from 6 to 8 seconds it is 1.33 kg m/s; and from 8 to 10 seconds it is zero. (Note that you don't really need to calculate values as a visual inspection will enable one to rank the areas.)

B5-WWT19: FORCE-TIME GRAPH II—IMPULSE APPLIED TO BOX

A 10-kg box, initially at rest, moves along a frictionless horizontal surface. A horizontal force to the right is applied to the box. The magnitude of the force changes as a function of time as shown.



A student calculates that the impulse applied by the force during the first 2 seconds is 4 N·s and that the impulse applied during the following 3 seconds is 6 N·s.

What, if anything, is wrong with these calculations? If something is wrong, identify it and explain how to correct it. If these calculations are correct, explain why.

Answer: The student's calculations are wrong.

The impulse is given by the area under the curve which for the first two seconds is 2 N·s since $(1/2) \cdot 2 \text{ s} \cdot 2 \text{ N} = 2 \text{ N}\cdot\text{s}$. The student's calculation for the next three seconds is correct.

B5-WWT20: TWO SKATERS PUSHING OFF EACH OTHER—FORCE

Two skaters, a large girl and a small boy, are initially standing face-to-face but then push off each other. After they are no longer touching, the boy has more kinetic energy than the girl. A physics student who is watching makes the following contention about the forces that the boy and girl exerted on each other:

“Since the boy has more kinetic energy, he also has more momentum, so the girl had to have pushed harder on him than he pushed on her.”

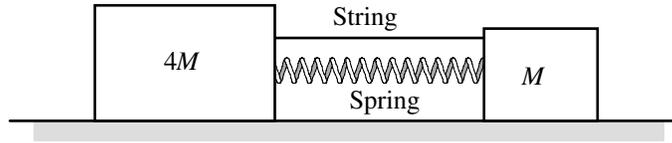
What, if anything, is wrong with this contention? If something is wrong, identify all problems and explain how to correct them. If this contention is correct, explain why.

Answer: The boy does not have a larger momentum than the girl after they push off each other; their momenta are equal.

Newton’s Third Law requires that the forces the two exerted on each other had to have been equal in magnitude and oppositely directed, and since those forces acted for the same time intervals, the change in momentum had to be equal in magnitude but oppositely directed for the two skaters. Consequently, since they both started from rest, their final momenta are equal in magnitude.

B5-CT21: TWO BOXES ON A FRICTIONLESS SURFACE—MOMENTUM AND SPEED

Two boxes are tied together by a string and are sitting at rest on a frictionless surface. Between the two boxes is a massless compressed spring. The string tying the two boxes together is cut and the spring expands, pushing the boxes apart. The box on the left has four times the mass of the box on the right.



(a) After the string is cut and the boxes lose contact with the spring, will the magnitude of the momentum of the box on the left be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the momentum of the box on the right? _____

Explain your reasoning.

Answer: (iii) Equal.

The same force—as required by Newton’s third law—acts on both boxes for the same time interval, so they both experience the same impulse.

(b) At the instant (after the string is cut) that the boxes lose contact with the spring, will the speed of the box on the left be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the speed of the box on the right? _____

Explain your reasoning.

Answer: (ii) less than.

The box on the left will have one-fourth the speed of the box on the right. Before the string is cut, the momentum of the system is zero. Momentum will be conserved, so the boxes will have equal but opposite momenta after they lose contact with the spring. So the box with the larger mass will have a lower speed.

B5-WWT22: BALL HITTING A WALL—MOMENTUM

A student observing a rubber ball hitting a wall and rebounding states:

“The change in momentum for the ball is equal and opposite to the change in momentum for the wall, because in this situation momentum has to be conserved.”

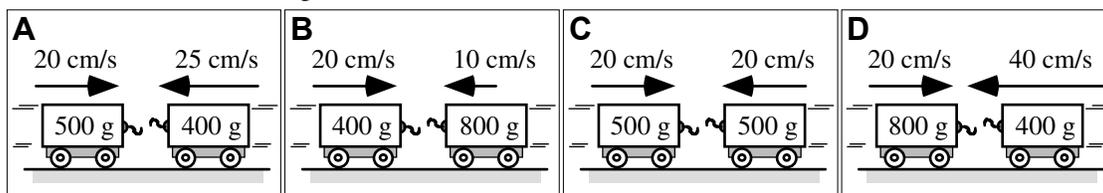
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: This statement is incorrect.

Momentum is conserved for a system if there is no net impulse acting on that system. If we consider the ball and the wall as a single system, during the collision the ground will exert a horizontal force on the wall and there will be a net impulse on the system. Momentum is not conserved for the system of the ball and wall.

B5-RT23: COLLIDING CARTS STICKING TOGETHER—FINAL SPEED

Two carts traveling in opposite directions are about to collide. The carts are all identical in size and shape, but they carry different loads and are traveling at different speeds. The carts stick together after the collision. There is no friction between the carts and the ground.



Rank the speed of the two-cart systems after the collision.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

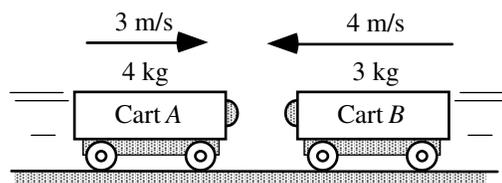
Explain your reasoning.

Answer: The final speed is zero for all of the cart systems.

The total initial momentum of the system of two carts is zero for all cases, so after the collision the two carts, which are stuck together, will be at rest.

B5-SCT24: TWO MOVING CARTS—RESULT OF COLLISION

Carts A and B are shown just before they collide. Four students discussing this situation make the following contentions:



Alma: “After the collision, the carts will stick together and move off to the left. Cart B has more speed, and its speed is going to determine which cart dominates in the collision.”

Baxter: “I think they’ll stick together and move off to the right because Cart A is heavier. It’s like when a heavy truck hits a car: The truck is going to win no matter which one’s going fastest, just because it’s heavier.”

Callie: “I think the speed and the mass compensate, and the carts are going to be at rest after the collision.”

Dante: “The carts must have the same momentum after the collision as before the collision, and the only way this is going to happen is if they keep the same speeds. All the collision does is change their directions, so that Cart A will be moving to the left at 3 m/s and Cart B will be moving to the right at 4 m/s.”

With which, if any, of these students do you agree?

Alma ____ Baxter ____ Callie ____ Dante ____ None of them ____

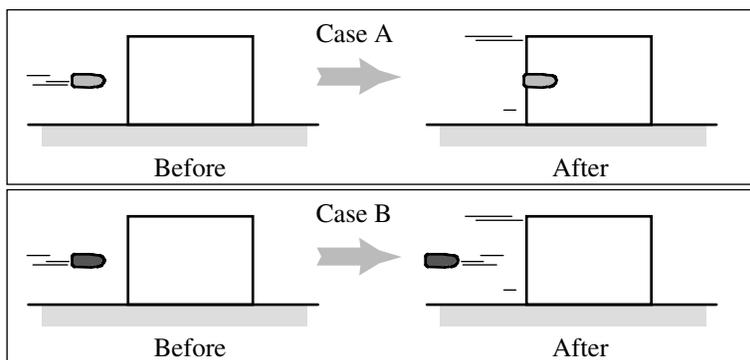
Explain your reasoning.

Answer: None of these contentions is correct.

We do not have enough information to determine the velocity of either cart after the collision. Momentum will be conserved for the collision, but this could happen in a number of ways, such as the carts sticking together and remaining at rest, or the carts bouncing off one another. What actually happens depends on the construction of the carts and on the material of the surfaces that come into contact (rubber, clay, Velcro, etc.).

B5-CT25: BULLET STRIKES A WOODEN BLOCK—BLOCK AND BULLET SPEED AFTER IMPACT

In Case A, a metal bullet penetrates a wooden block. In Case B, a rubber bullet with the same initial speed and mass bounces off of an identical wooden block.

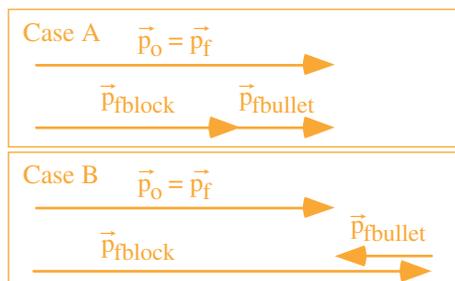


(a) Will the speed of the wooden block after the collision be (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: (ii) Greater in case B.

The initial momentum in both cases is the same and points to the right. The final momentum of the bullet points to the right in case A and to the left in case B. Since the final momentum of the system consisting of the bullet and the block is the same as the initial momentum, and this final momentum is the vector sum of the momentum of the bullet and the momentum of the block, the momentum of the block must be greater in case B.



(b) In Case B, will the speed of the bullet after the collision be (i) *greater than*, (ii) *less than*, or (iii) *the same as* the speed of the bullet just before the collision? _____

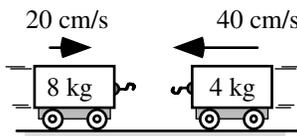
Explain your reasoning.

Answer: (ii) Less than.

The energy of the system containing both block and bullet cannot be greater after the collision than before. The initial energy is the kinetic energy of the bullet, and the final energy is the sum of the kinetic energies of the bullet and the block. Since the block has a non-zero final kinetic energy, the final kinetic energy of the bullet must be less than the initial kinetic energy of the bullet.

B5-SCT26: COLLIDING CARTS THAT STICK TOGETHER—FINAL KINETIC ENERGY

Two identical carts traveling in opposite directions are shown just before they collide. The carts carry different loads and are initially traveling at different speeds. The carts stick together after the collision.



Three physics students discussing this situation make the following contentions:

- Alex: “These carts will both be at rest after the collision since the initial momentum of the system is zero, and the final momentum has to be zero also.”
- Belinda: “If that were true it would mean that they would have zero kinetic energy after the collision, and that would violate conservation of energy. Since the right-hand cart has more kinetic energy, the combined carts will be moving slowly to the left after the collision.”
- Chano: “I think that after the collision the pair of carts will be traveling left at 20 cm/s. That way conservation of momentum and conservation of energy are both satisfied.”

With which, if any, of these students do you agree?

Alex _____ Belinda _____ Chano _____ None of them _____

Explain your reasoning.

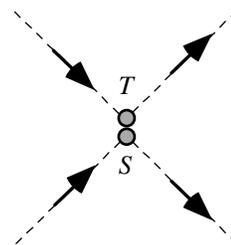
Answer: Alex is correct.

The momenta of the two carts are equal and opposite before the collision, so the total initial momentum is zero and the total final momentum has to be zero also.

B5-QRT27: COLLIDING STEEL BALLS—MOMENTUM AND IMPULSE DIRECTION

Two identical steel balls, *S* and *T*, are shown at the instant that they collide. The paths and velocities of the two balls before and after the collision are indicated by the dashed lines and arrows. The speeds of the balls are same before and after the collision.

For the questions below, use the directions indicated by the arrows in the direction rosette, or use **J** for no direction, **K** for into the page, or **L** for out of the page.

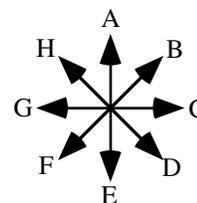


(a) Which letter best represents the direction of the initial momentum of ball *T*? _____

Explain your reasoning.

Answer: D.

The direction of the momentum is the same as the direction of the velocity. As indicated by the arrow, ball T is moving down and to the right before the collision.



(b) Which letter best represents the direction of the final momentum of ball *T*? _____

Explain your reasoning.

Answer: B.

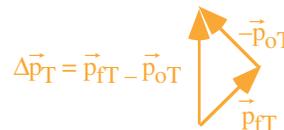
The direction of the momentum is the same as the direction of the velocity. As indicated by the arrow, ball T is moving up and to the right after the collision.

(c) Which letter best represents the direction of the change in momentum for ball *T*? _____

Explain your reasoning.

Answer: A.

The change in momentum of ball T is its final momentum minus its initial momentum, and is found by subtracting vectors as shown.



(d) Which letter best represents the direction of the change in momentum for ball *S*? _____

Explain your reasoning.

Answer: E.

The change in momentum of ball S is its final momentum minus its initial momentum, and is found by subtracting vectors as shown.



(e) Which letter best represents the direction of the impulse on ball *T*? _____

Explain your reasoning.

Answer: A.

The impulse-momentum equation is a vector equation, and the direction of the impulse must be the same as the direction of the change in momentum (as found in part (c)).

(f) Which letter best represents the direction of the impulse on ball *S*? _____

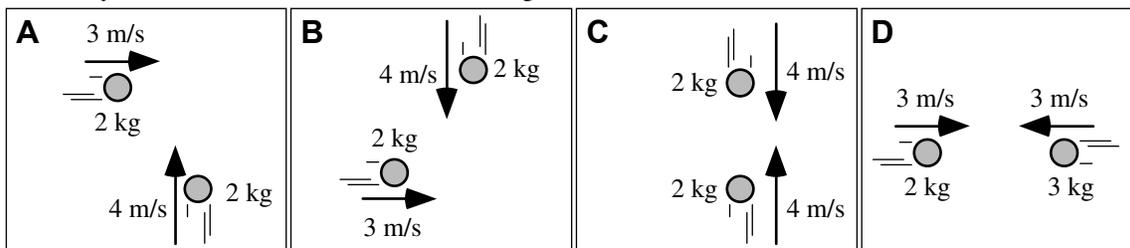
Explain your reasoning.

Answer: E.

The impulse-momentum equation is a vector equation, and the direction of the impulse must be the same as the direction of the change in momentum (as found in part (d)).

B5-RT28: COLLIDING BALL SYSTEMS—MOMENTUM BEFORE AND AFTER COLLIDING

In the figures below, two balls traveling in different directions are about to collide. The balls are identical in size and shape, but they have different masses and are traveling at different velocities as shown.



(a) Rank the magnitude of the momentum of the two-ball systems before they collide.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: A = B > D > C.

Since we add these vectorially giving 10 (kg)(m)/s at an angle for A and B, C is zero, and D is 3 (kg)(m)/s.

(b) Rank the magnitude of the momentum of the two-ball systems after they collide if the balls stick together.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: A = B > D > C.

Same as (a) since momentum of the system is conserved.

(c) Rank the magnitude of the momentum of the two-ball systems after they collide elastically (energy conserved).

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

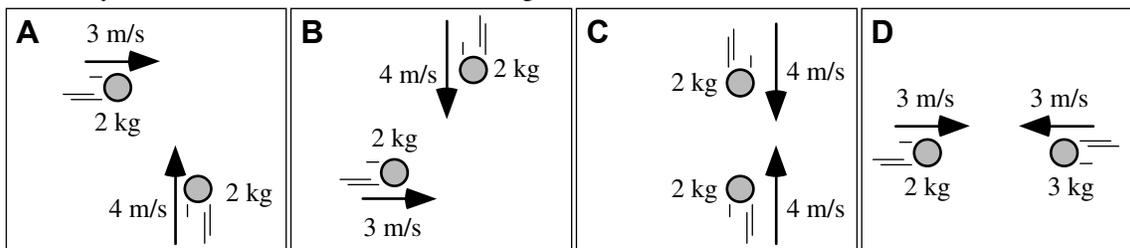
Explain your reasoning.

Answer: A = B > D > C.

Same as (a) since momentum of the system is conserved

B5-QRT29: COLLIDING BALL SYSTEMS—MOMENTUM DIRECTION BEFORE AND AFTER COLLIDING

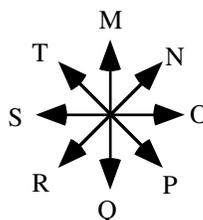
In the figures below, two balls traveling in different directions are about to collide. The balls have the same size and shape, but they have different masses and are traveling at different velocities as shown.



For the questions below, use the directions indicated by the arrows in the direction rosette, or use **J** for no direction, **K** for into the page, or **L** for out of the page.

(a) Identify the closest directional match for the direction of the momentum of the two-ball systems before they collide.

A	B
C	D

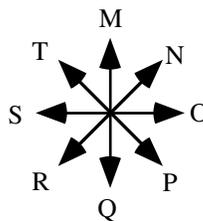


Explain your reasoning.

Answer: A is N, B is P, C is J since the momentum is zero, D is S. The question is asking about the total momentum of the system which is the vector addition of the two momenta.

(b) Identify the closest directional match for the direction of the momentum of the two-ball systems after they collide if the balls stick together.

A	B
C	D



A is N, B is P, C is J since it is zero, D is S.

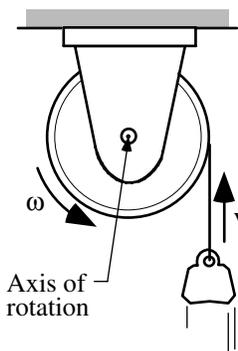
Explain your reasoning.

Momentum is conserved so the momentum of the system is the same direction after as before collision in all the cases. The direction of the momentum of the system is the vector sum of the momentum of the two parts.

B6 ROTATION

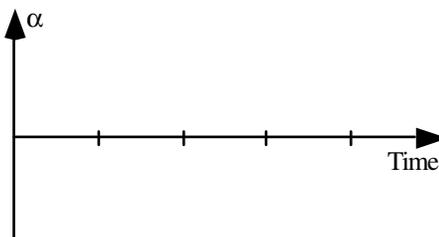
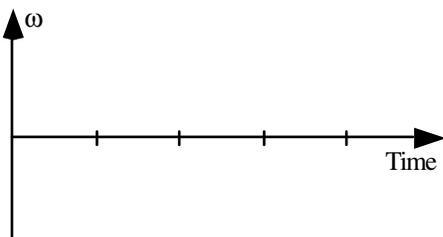
B6-CRT01: PULLEY AND WEIGHT—ANGULAR VELOCITY-TIME AND ACCELERATION-TIME GRAPHS

A weight is tied to a rope that is wrapped around a pulley. The pulley is initially rotating counterclockwise and is pulling the weight up. The tension in the rope creates a torque on the pulley that opposes this rotation. The weight slows down, stops momentarily, and then moves back downward.



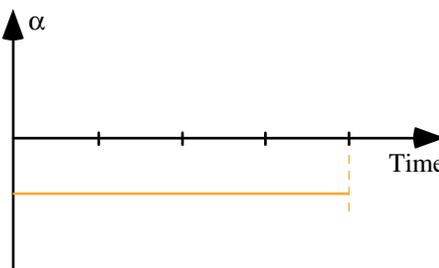
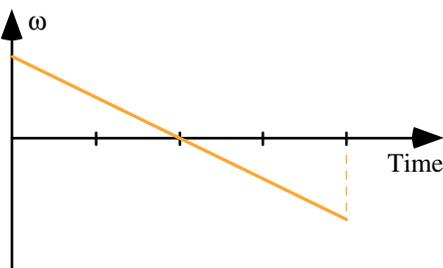
(a) Graph of the angular velocity (ω) versus time for the period from the initial instant shown until the weight comes back down to the same height. Take the initial angular velocity as positive.

(b) Graph the angular acceleration (α) versus time for the same time period.



Explain your reasoning.

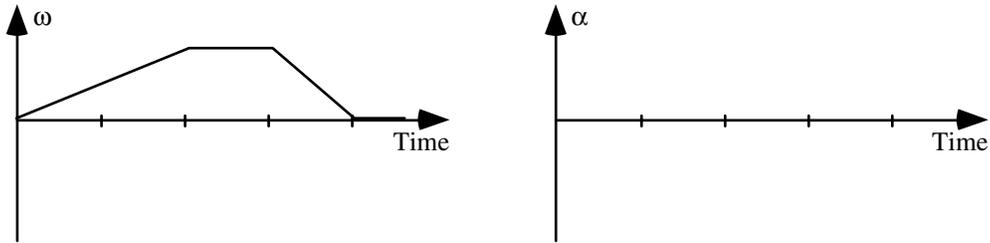
Answer:



The tension in the string resulting from the weight of the hanging block produces a constant torque on the pulley. So the pulley will rotate counterclockwise but slow down to stop at an instant, and then start rotating clockwise at an increasing rate. If we take the initial angular velocity as positive, then the angular acceleration has to be constant and negative.

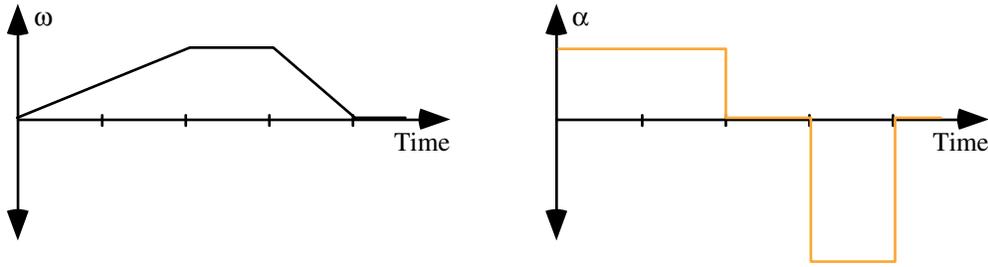
B6-CRT02: ANGULAR VELOCITY-TIME GRAPH—ANGULAR ACCELERATION-TIME GRAPH

Sketch an angular acceleration versus time graph given the angular velocity versus time graph shown for the same time interval.



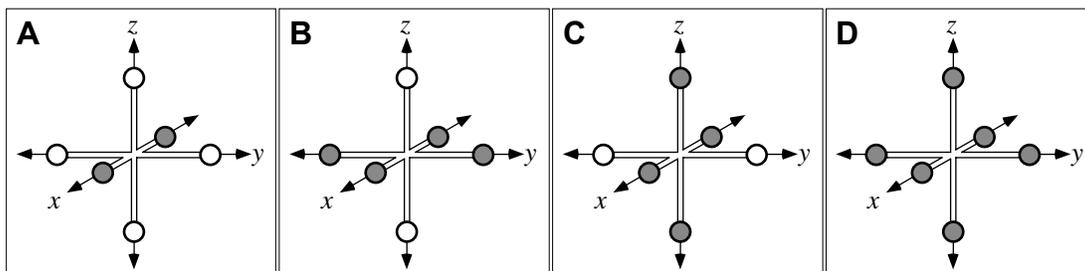
Explain your reasoning.

Answer: The slope of the line in the angular velocity graph tell us the angular acceleration. The first segment has a positive slope for two time units, then a zero slope for one time unit, a negative slope for one time unit, and finally a zero slope at zero velocity. The positive slope has a smaller magnitude than the negative slope, so the acceleration-time graph should look like the following:



B6-RT03: THREE-DIMENSIONAL POINT OBJECTS—MOMENT OF INERTIA ABOUT THE x-AXIS

Six small brass and aluminum spheres are connected by three stiff, lightweight rods to form a rigid object shaped like a jack. The rods are joined at their centers, are mutually perpendicular, and lie along the axes of the coordinate system shown. All spheres are the same distance from the connection point of the three rods at the origin of the coordinate axis. The brass spheres are shaded in the diagram and are identical. The aluminum spheres are identical, have less mass than the brass spheres, and are unshaded in the diagram. For this problem, ignore the mass of the connecting rods.



Rank the moment of inertia about the x-axis.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

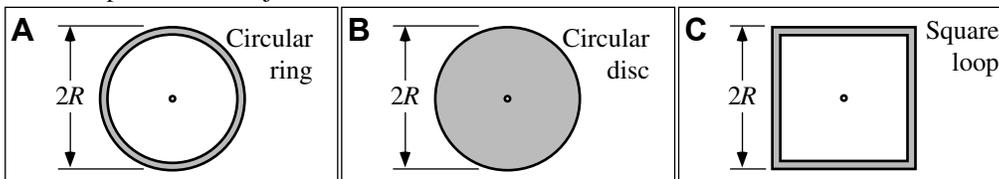
Explain your reasoning.

Answer: $F > C = D = E > A = B$.

The moment of inertia depends on the product of the mass and the square of the distance from that mass to the axis of rotation. For a rigid object, we can find the moment of inertia by adding this product together for all the mass in the object. Since the axis of rotation in this case is the x-axis, we can ignore all masses along this axis since the distance to them is zero. To rank the moments of inertia we need to rank the total mass that is not along the x-axis, since all of this mass is at the same distance. Case F has 4 brass spheres not on the x-axis, Cases C, D, and E each have two, and A and B have none.

B6-RT04: FLAT OBJECTS—MOMENT OF INERTIA PERPENDICULAR TO SURFACE

Three flat objects (circular ring, circular disc, and square loop) have the same mass M and the same outer dimension (circular objects have diameters of $2R$ and the square loop has sides of $2R$). The small circle at the center of each figure represents the axis of rotation for these objects. This axis of rotation passes through the center of mass and is perpendicular to the plane of the objects.



Rank the moment of inertia of these objects about this axis of rotation.

<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>
1	2	3	All	Cannot	determine
Greatest		Least	the same		

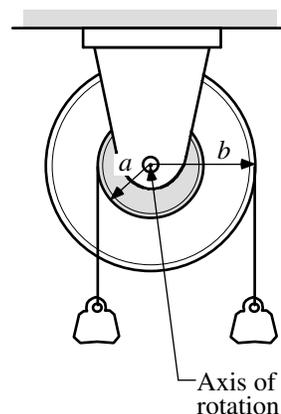
Explain your reasoning.

Answer: $C > A > B$.

Based on the distribution of mass. Mass farther from axis contributes more to the moment of inertia than mass closer to the axis. For the circular ring, all of the mass is at a distance R from the axis of rotation; and for the square loop almost all of the mass is at a distance that is greater than R . All of the mass of the disc is at a distance R or less.

B6-QRT05: PULLEYS WITH DIFFERENT RADII—ROTATION AND TORQUE

A wheel is composed of two pulleys with different radii (labeled a and b) that are attached to one another so that they rotate together. Each pulley has a string wrapped around it with a weight hanging from it as shown. The pulleys rotate about a horizontal axis at the center. When the wheel is released it is found to have an angular acceleration that is directed out of the page or counterclockwise.



(a) Is the wheel going to rotate (i) *clockwise*, (ii) *counterclockwise*, or (iii) *none*?

Explain your reasoning.

Answer: The wheel is rotating counterclockwise, as application of the right-hand rule shows.

(b) Is the direction of the net torque on the pulley wheels (i) *clockwise*, (ii) *counterclockwise*, or (iii) *none*? _____

How do you know?

Answer: The net torque is directed out of the page since the net torque must be in the same direction as the angular acceleration.

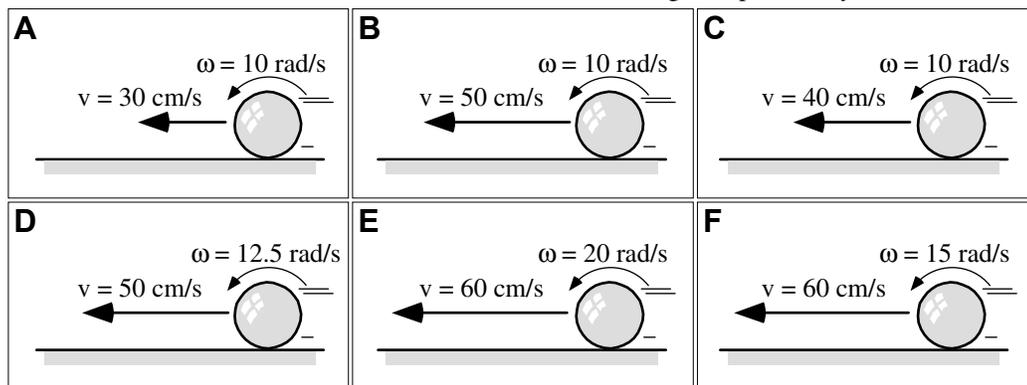
(c) How do the masses of the two weights compare?

Explain your reasoning.

Answer: Since the angular acceleration is out of the page, the net torque is out of the page. The tension in the string attached to the smaller pulley is producing a torque that is out of the page, and the tension in the string attached to the larger pulley is producing a torque that is into the page. Since the net torque is out of the page, the torque due to the tension in the string on the left is greater than the torque due to the tension in the string on the right. Therefore tension in the string on the left times the radius a must be greater than the tension in the string on the right times b . Since a is smaller than b , it must be true that the tension in the string on the left is

B6-RT06: SPHERES ROLLING—RADIUS

The figures below show hollow spheres (not drawn to scale) that are rolling at a constant rate without slipping. The spheres all have the same mass, but their radii as well as their linear and angular speeds vary.



Rank the radius of the spheres.

						OR	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
1	2	3	4	5	6		All the same	All zero	Cannot determine		
Greatest						Least					

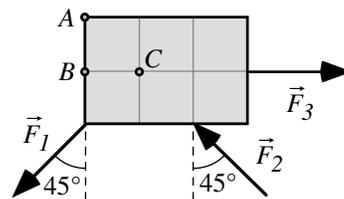
Explain your reasoning.

Answer: B > C = D = F > A = E.

Ranked on v/ω since v = ωR when objects roll without slipping.

B6-QRT07: THREE EQUAL FORCES APPLIED TO A RECTANGLE—NET TORQUE DIRECTION

Three forces of equal magnitude are applied to a 3-m by 2-m rectangle. Forces \vec{F}_1 and \vec{F}_2 act at 45° angles to the vertical as shown, while \vec{F}_3 acts horizontally.



(a) Is the net torque about point A (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Clockwise.

Since the line of action for F_2 is through point A, F_2 creates no torque about point A. The line of action for force F_3 passes through point B, 1 meter away from P. The shortest distance from A to the line of action for force F_1 is 1.41 meters, the distance from point A to point C. Force F_1 will produce a clockwise torque about point A, and force F_3 will produce a counterclockwise torque about point A. Since all of the forces are equal, the force acting at the largest perpendicular distance generates the largest torque.

(b) Is the net torque about point B (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Zero.

The line of action for F_3 is through point B, so F_3 creates no torque about point B. The line of action for forces F_2 and F_1 both pass a distance of 0.707 meters from point B, but one creates a clockwise torque about B and one a counterclockwise torque. So the torques due to these two forces will cancel, and the net torque about B is zero.

(c) Is the net torque about point C (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

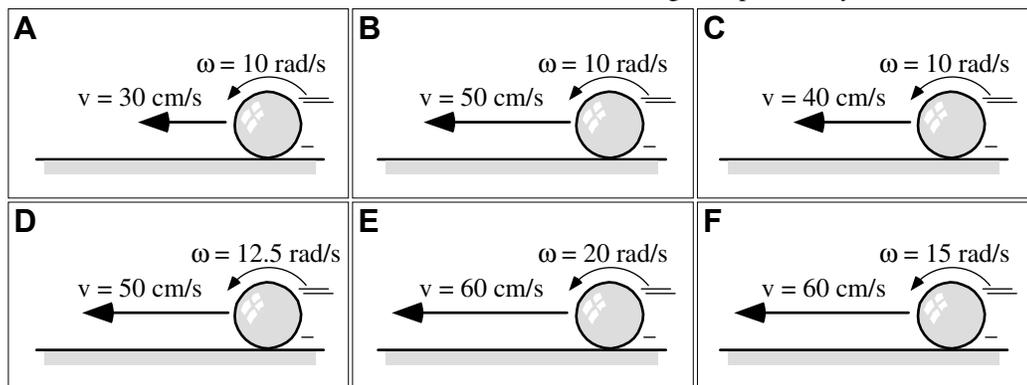
Explain how you determined your answer.

Answer: Zero.

The line of action for all forces pass through point C, so the torque due to each force is zero, and the net torque is also zero.

B6-RT08: SPHERES ROLLING—ROTATIONAL KINETIC ENERGY

The figures below show hollow spheres (not drawn to scale) that are rolling at a constant rate without slipping. The spheres all have the same mass, but their radii as well as their linear and angular speeds vary.



Rank the rotational kinetic energy of the spheres.

<input style="width: 100%; height: 20px;" type="text"/>	OR	<input style="width: 100%; height: 20px;" type="checkbox"/>	<input style="width: 100%; height: 20px;" type="checkbox"/>	<input style="width: 100%; height: 20px;" type="checkbox"/>					
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

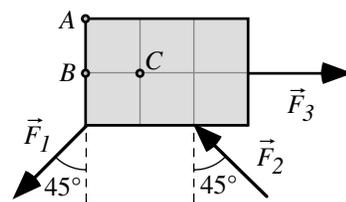
Explain your reasoning.

Answer: $E = F > B = D > C > A$.

Ranked on v since KE is proportional to ω squared or v squared and the mass is constant.

B6-QRT09: THREE FORCES APPLIED TO A RECTANGLE—TORQUE DIRECTION

Three forces of equal magnitude are applied to a 3-m by 2-m rectangle. Forces \vec{F}_1 and \vec{F}_2 act at 45° angles to the vertical as shown, while \vec{F}_3 acts horizontally.



(a) Is the torque by \vec{F}_1 about point A (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Clockwise. The component of F_1 that is horizontal would pull the bottom of the rectangle to the left.

(b) Is the torque by \vec{F}_1 about point B (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Clockwise. The situation is the same as for A except that the moment arm is shorter.

(c) Is the torque by \vec{F}_1 about point C (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Zero. The line of action of the force goes through C so there is a zero moment arm.

(d) Is the torque by \vec{F}_2 about point A (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Zero. The line of action of the force goes through A.

(e) Is the torque by \vec{F}_2 about point B (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Counterclockwise. F_2 will push the rectangle up making it rotate CCW about B.

(f) Is the torque by \vec{F}_2 about point C (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Zero. The line of action of the force goes through C.

(g) Is the torque by \vec{F}_3 about point A (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Counterclockwise. F_3 will pull the rectangle up around A.

(h) Is the torque by \vec{F}_3 about point B (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Zero. The line of action of the force goes through B.

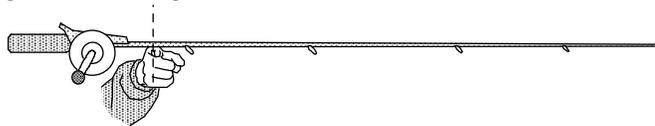
(i) Is the torque by \vec{F}_3 about point C (i) clockwise, (ii) counterclockwise, or (iii) zero? _____

Explain your reasoning.

Answer: Zero. The line of action of the force goes through C.

B6-CT10: FISHING ROD—WEIGHT OF TWO PIECES

An angler balances a fishing rod on her finger as shown.



If she were to cut the rod along the dashed line, would the weight of the piece on the left-hand side be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the weight of the piece on the right-hand side? _____

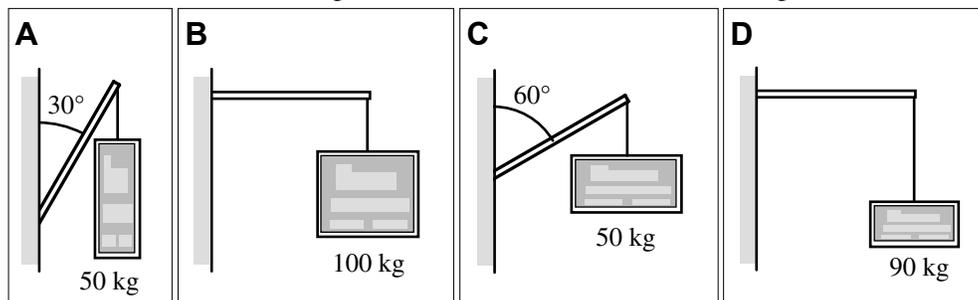
Explain your reasoning.

Answer: Greater than.

The net torque about the balancing point of the rod is zero, since the rod has no angular acceleration. The weight of the rod to the left of the balancing point creates a counterclockwise torque about that point, and the weight of the rod to the right creates a clockwise torque. The magnitudes of these torques must be equal for the net torque to be zero. The weight of the left side of the rod (the handle) acts at the center of mass of the left side, and the weight of the right side acts at the center of mass of the right side. Since the right side is longer than the left, the center of mass of the right side is further away from the dashed line than the center of mass of the left side. For the torques to be equal, the weight of the left side must be greater to compensate for the smaller perpendicular distance.

B6-RT11: SUSPENDED SIGNS—TORQUE

Signs are suspended from equal-length rods on the side of a building. For each case, the mass of the rod compared to the mass of the sign is small and can be ignored. The mass of the sign is given in each figure. In Cases B and D, the rod is horizontal; in the other cases, the angle that the rod makes with the vertical is given.



Rank the magnitude of the torque the signs exert about the point at which the rod is attached to the side of the building.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

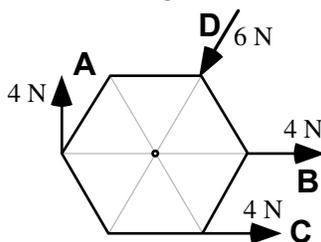
Explain your reasoning.

Answer: $B > D > C > A$.

The torque depends on the weight of the sign (mg) times the distance from the line of action of this weight to the point of attachment. The line of action of the weight is along the rope that is suspending the sign, which is one rod length (L) away from the attachment point in cases B and D, closer than that in case C, and closer yet ($0.5L$) in case A. Since A and C have the smallest masses and C has the smallest distance, A will be larger than C, which will be the smallest. Since B and D have the largest masses and the largest distances, they will have the largest torques, with $B > D$.

B6-RT12: FOUR FORCES ACTING ON A HEXAGON—TORQUE ABOUT CENTER

Four forces act on a plywood hexagon as shown in the diagram. The sides of the hexagon each have a length of 1 m.



Rank the magnitude of the torque applied about the center of the hexagon by each force.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: $A > C > B = D$.

The magnitude of the torque due to each force is equal to the magnitude of the force times the perpendicular distance between the line of action of that force and the pivot point. The lines of action of forces B and D pass through the center of the hexagon, so the torques due to forces B and D are both zero. The perpendicular distance between the line of action and the pivot point is equal to the height of one of the triangles shown for force C, and is equal to the side of a triangle for force A. The side of the triangle is longer than the height, so the torque due to force A is greatest.

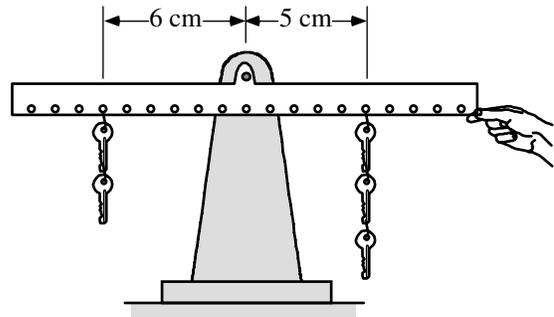
B6-QRT13: BALANCE BEAM—MOTION AFTER RELEASE

Five identical keys are suspended from a balance, which is held horizontally as shown. The two keys on the left are attached to the balance 6 cm from the pivot and the three keys on the right are attached 5 cm from the pivot.

What will happen when the person lets go of the balance beam?

Explain.

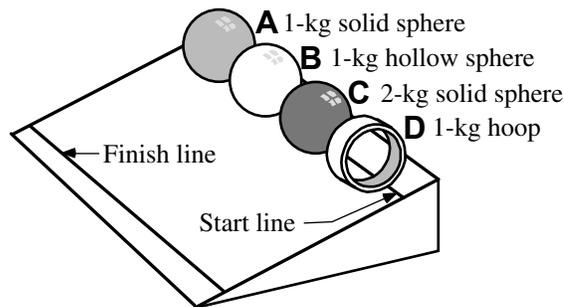
Answer: It will rotate clockwise, since the clockwise torque due to the three keys is greater than the torque due to the two keys.



B6-RT14: ROLLING OBJECTS RELEASED FROM REST—TIME DOWN RAMP

Four objects are placed in a row at the same height near the top of a ramp and are released from rest at the same time. The objects are (i) a 1-kg solid sphere; (ii) a 1-kg hollow sphere; (iii) a 2-kg solid sphere; and (iv) a 1-kg thin hoop. All four objects have the same diameter, and the hoop has a width that is one-quarter its diameter. The time it takes the objects to reach the finish line near the bottom of the ramp is recorded. The moment of inertia for an axis passing through its center of mass for a solid sphere is $\frac{2}{5}MR^2$; for a hollow sphere it is

$\frac{2}{3}MR^2$; and for a hoop it is MR^2 .



Rank the four objects from fastest (shortest time) down the ramp to slowest.

				OR		
1	2	3	4		All the same	Cannot determine
Fastest			Slowest			

Explain your reasoning.

Answer: A = C > B > D

Each of these objects begins with gravitational potential energy at the top of the ramp that is converted to kinetic energy at the bottom. The objects will have both translational and rotational KE at the bottom. Energy is conserved so we can set $mgh = 1/2mv^2 + 1/2I\omega^2$. Assuming that all of the objects roll without slipping the translational KE will be proportional to the rotational KE. After some algebra we find that the masses cancel for each case, since $mgh =$ final kinetic energy which also involves the mass. That means the determining factor is the fraction in the moment of inertia for each object, since that determines which object will have more translational kinetic energy, and consequently will get down the incline faster.

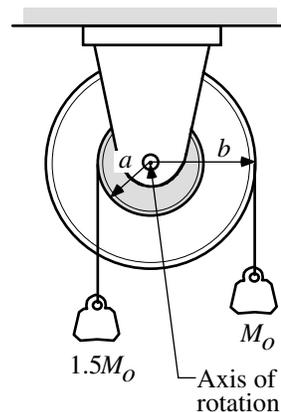
B6-WWT15: PULLEY WITH HANGING WEIGHTS—ANGULAR ACCELERATION

Two pulleys with different radii (labeled a and b) are attached to one another so that they rotate together. Each pulley has a string wrapped around it with a weight hanging from it. The pulleys are free to rotate about a horizontal axis through the center. The radius of the larger pulley is twice the radius of the smaller one ($b = 2a$). A student describing this arrangement states:

“The larger mass is going to create a counterclockwise torque and the smaller mass will create a clockwise torque. The torque for each will be the weight times the radius, and since the radius for the larger pulley is double the radius of the smaller, and the weight of the heavier mass is less than double the weight of the smaller one, the larger pulley is going to win. The net torque will be clockwise, and so the angular acceleration will be clockwise.”

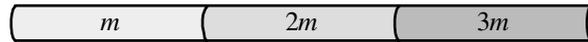
What, if anything, is wrong with this contention? If something is wrong, explain how to correct it. If this contention is correct, explain why.

Answer: The student's answer and reasoning are both correct.



B6-CT17: SPECIAL ROD—MOMENT OF INERTIA

A rod is made of three segments of equal length with different masses. The total mass of the rod is $6m$.



Will the moment of inertia of the rod be (i) *greater* about the left end, (ii) *greater* about the right end, or (iii) *the same* about both ends? _____

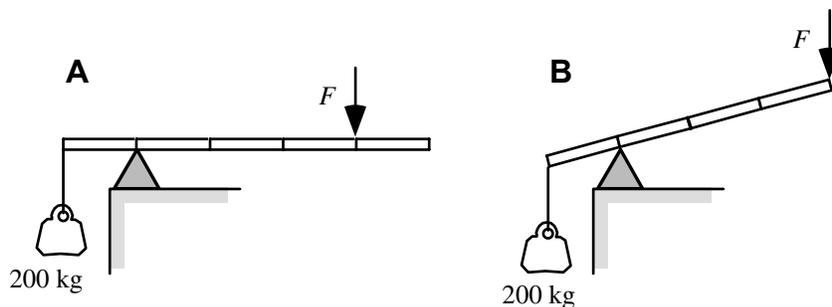
Explain your reasoning.

Answer: (i) The moment of inertia will be greater about the left end.

The moment of inertia is a measure of how difficult it is to change the rate of rotation of an object. When mass is close to the axis of rotation, it is not as difficult to speed up or slow down in rotation. The moment of inertia is greatest when more mass is further from the axis of rotation.

B6-CT18: TILTED PIVOTED RODS WITH VARIOUS LOADS—FORCE TO HOLD RODS

In both cases, a massless rod is supported by a fulcrum, and a 200-kg hanging mass is suspended from the left end of the rod by a cable. A downward force F keeps the rod at rest. The rod in Case A is 50 cm long, and the rod in Case B is 40 cm long. (Each rod is marked at 10-cm intervals.)



Will the magnitude of the vertical force F exerted on the rod be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

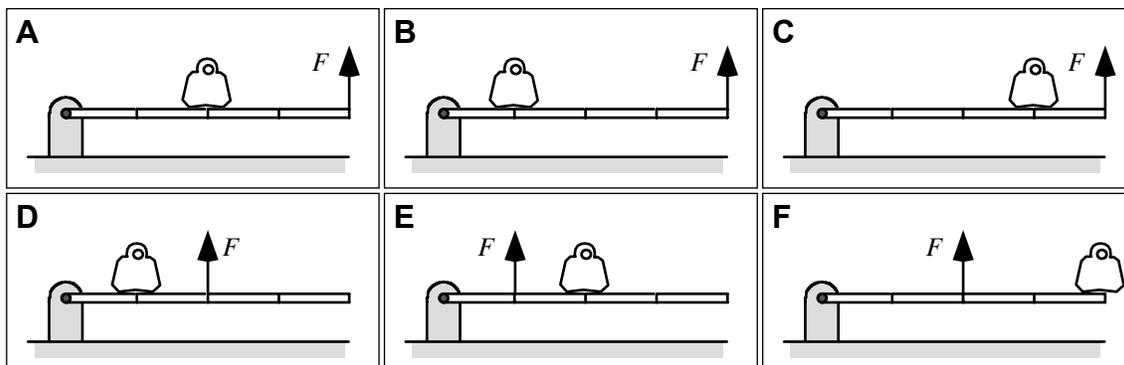
Explain your reasoning.

Answer: The same in both cases.

In each case, the tension in the cable is equal to the weight of the hanging mass, about 2000 N. In both cases, the distance between the line of action of the weight of the hanging mass and the fulcrum is one-third the distance between the line of action of the applied force F and the fulcrum. Since there is no rotational acceleration, the net torque must be zero in each case, so the clockwise torque due to the applied force F must be equal in magnitude to the counterclockwise torque due the cable tension. The applied force must be one-third the weight in both cases.

B6-RT19: HORIZONTAL PIVOTED RODS WITH LOADS I—FORCE TO HOLD

A 2-m long massless rod supports a 12-Newton weight. The left end of each rod is held in place by a frictionless pin. In each case, a vertical force F is holding the rods and the weights at rest. The rods are marked at half-meter intervals.



Rank the magnitude of the vertical force F applied to the rods.

1	2	3	4	5	6	OR	All the same	Cannot determine
Greatest							Least	

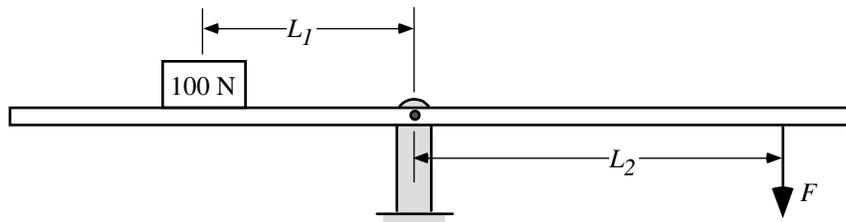
Explain your reasoning.

Answer: $E = F > C > A = D > B$.

All of the systems are in equilibrium so in each case the torque about the frictionless pin must be zero. The weight creates a clockwise torque equal to the weight times the distance along the rod from the pivot point, and the applied force F creates a counterclockwise torque equal to the magnitude of F times its distance from the pivot. These torques must be equal in magnitude, so F times the distance from the pivot to F must equal the weight times the distance to the weight. In cases E and F, the weight is twice as far from the pivot as the applied force, so the applied force must be twice the weight. In cases A and D, the force is twice as far from the pivot as the weight, so the applied force is half the weight. In case C, the applied force is three-quarters of the weight, and in case B the applied force is one-quarter of the weight.

B6-LMCT20: HORIZONTAL PIVOTED BOARD WITH LOAD II—FORCE TO HOLD BOARD

A 100-N weight is placed on a massless board a distance L_1 to the left of frictionless pin. A vertical downward force F is applied to the other side of the board a distance of L_2 from the pin as shown. The system is at rest.



Identify from choices (i)–(v) how each change described below will affect the magnitude of the applied force (F) on the right side of the board needed to keep the system in equilibrium.

Compared to the case above, this change will:

- (i) *increase* the magnitude of the support force (F) on the board.
- (ii) *decrease* the magnitude of the support force (F) on the board but not to zero.
- (iii) *decrease* the magnitude of the support force (F) on the board **to zero**.
- (iv) *have no effect* on the magnitude of the support force (F) on the board.
- (v) *have an indeterminate* effect on the magnitude of the support force (F) on the board.

Each of these modifications is the only change to the initial situation shown in the diagram above.

(a) The 100-N weight is moved to a position closer to the pin. _____

Explain your reasoning.

Answer: (ii). This will reduce the torque due to the 100 N weight.

(b) The support force (F) is moved to a position closer to the pin. _____

Explain your reasoning.

Answer: (i). A smaller moment arm requires a larger force to produce the same torque.

(c) The weight is decreased to 50 N. _____

Explain your reasoning.

Answer: (ii). This will reduce the torque to be balanced.

(d) The support force (F) is moved to the right end of the board. _____

Explain your reasoning.

Answer: (ii). Increasing the moment arm will reduce the force required.

(e) The board is made longer but the support force (F) remains at the same location. _____

Explain your reasoning.

Answer: (iv). This doesn't change either torque.

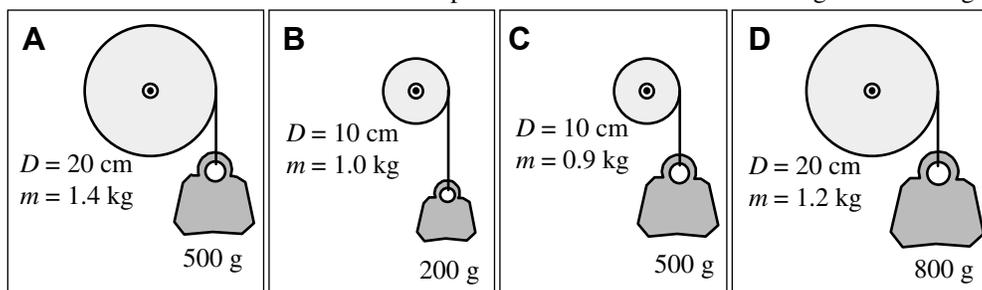
(f) The 100-N weight and the support force (F) are both moved to positions closer to the pin. _____

Explain your reasoning.

Answer: (v). We would need to know how the new ratio of the distances compared to the old ratio to be able to determine the effect on the magnitude of F .

B6-RT21: HANGING WEIGHTS ON FIXED DISKS—TORQUE

Vertically oriented circular disks have strings wrapped around them. The other ends of the strings are attached to hanging masses. The diameters of the disks, the masses of the disks, and the masses of the hanging masses are given. The disks are fixed and are *not* free to rotate. Specific values of the variables are given in the figures.



Rank the magnitudes of the torques exerted by the strings about the center of the disks.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

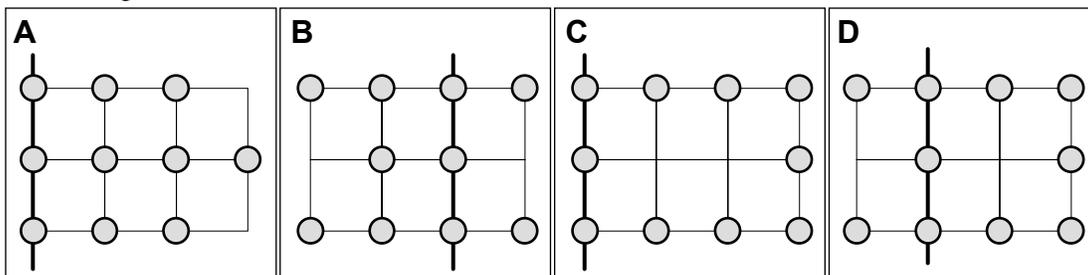
Explain your reasoning.

Answer: $D > A > C > B$.

The torque will be the product of the tension in the string, which will be equal to the magnitude of the hanging weight since the systems remain at rest, times the radius of the disk, which is half of the diameter given in each figure.

B6-RT22: SYSTEMS OF POINT MASSES—DIFFICULT TO ROTATE

Each of the ten point masses in each case is identical. The solid line in each figure represents an axis about which the masses are going to be rotated. The point masses are fixed together so that they all maintain the arrangements shown while being rotated.



Rank these arrangements on how hard it will be to start the systems rotating.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

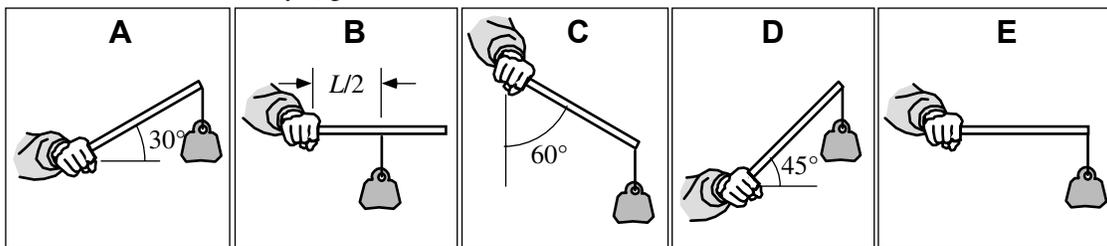
Explain your reasoning.

Answer: C > A > D > B.

The larger the moment of inertia of the system the more difficult it will be to rotate it. The moment of inertia for each one is the sum of the product of each point mass times its distance from the axis of rotation. Since they all have seven point masses to sum the farther more masses are from the axis the larger the moment of inertia.

B6-RT23: METER STICK WITH HANGING MASS I—DIFFICULTY HOLDING

A student is holding a meter stick by one end. A 1,000 g mass is hung on the meter sticks. All of the meter sticks are identical, but the distance along the meter stick at which the 1,000 g mass is hung and the angles at which the student holds the meter stick vary. (Ignore the mass of the meter stick.)



Rank the difficulty of holding the meter stick from the left end in the position shown.

<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>				
1	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

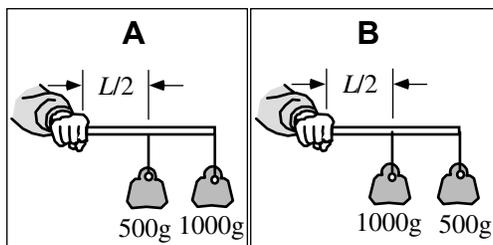
Explain your reasoning.

Answer: E > A = C > D > B.

The person holding the stick has to provide a torque to balance that exerted by the hanging mass. The torque due to the hanging mass is the weight of the mass times the perpendicular distance between the hand and the point on the stick where the mass is attached.

B6-CT24: HORIZONTAL METER STICK WITH TWO HANGING MASSES—TORQUE

In each case, a student is holding a meter stick horizontally. Each meter stick has a mass attached at the 50 cm mark and another at the 100 cm mark. The meter sticks are identical, and the specific values and locations are given in the figures.



Is the magnitude of the torque by the student on the meter stick (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

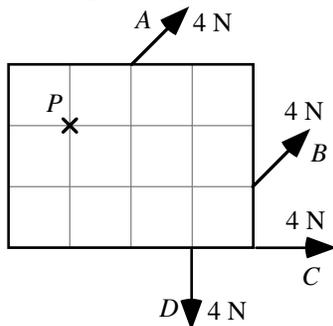
Explain your reasoning.

Answer: Greater in case A.

The person holding the stick has to provide a torque to balance that exerted by the hanging masses. The torque due to the hanging mass is the weight of the mass times the perpendicular distance between the hand and the point on the stick where the mass is attached. In A the larger mass is farther from the hand.

B6-RT25: FOUR FORCES ACTING ON A PIECE OF PLYWOOD—TORQUE

Four 4-Newton forces (A – D) act on a 3-m by 4-m piece of plywood as shown.



Rank the magnitudes of the torques due to the four forces about point P .

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

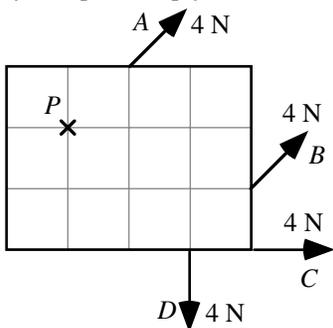
Explain your reasoning.

Answer: $B > C = D > A$.

The torque due to each force is the product of the force (which is the same in all cases) and the perpendicular distance between the line of action of the force and the pivot point. Since the line of action for force A acts through point P , this force exerts no torque about point P . The perpendicular distance is 2 meters in cases C and D , and 2.82 meters in case B . The ranking of the torques will be the same as the ranking of the perpendicular distances.

B6-QRT26: FOUR FORCES ACTING ON A PIECE OF PLYWOOD—ROTATION DIRECTION

Four 4-Newton forces (A – D) act on a 3 m by 4 m piece of plywood that has a pivot point at P .



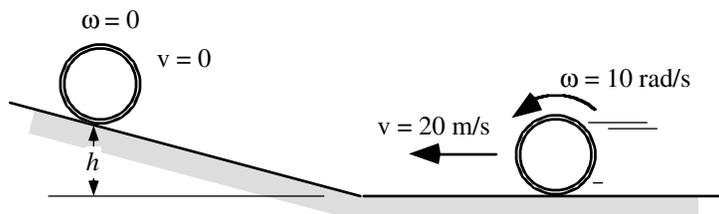
Will the plywood rotate about the pivot point P (i) *clockwise*, (ii) *counterclockwise*, or (iii) *not at all*? _____
Explain your reasoning.

Answer: Counter-clockwise.

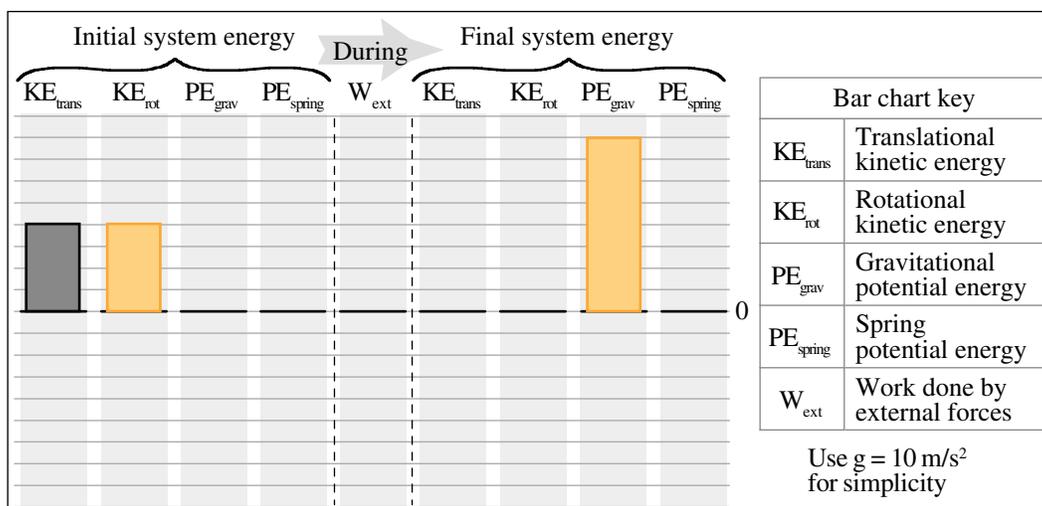
The net torque is the sum of the 4 individual torques. Force B exerts no torque, and C and D exert equal torques in opposite directions, so the net torque is equal to the torque due to force A , which is acting to create a counterclockwise torque.

B6-BCT27: HOOP ROLLING UP A RAMP—ROTATIONAL ENERGY BAR CHART

A thin hoop or ring with a radius of 2 m is moving so that its center of mass is initially moving at 20 m/s while also rolling without slipping at 10 rad/s along a horizontal surface. It rolls up an incline, coming to rest as shown.



Complete the qualitative energy bar chart below for the earth-hoop system for the time between when the hoop is rolling on the horizontal surface and when it has rolled up the ramp and is momentarily at rest. Put the zero point for the gravitational potential energy at the height of the center of the hoop when it is rolling on the horizontal surface.

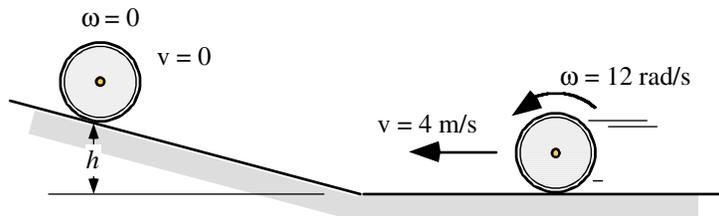


Explain your reasoning.

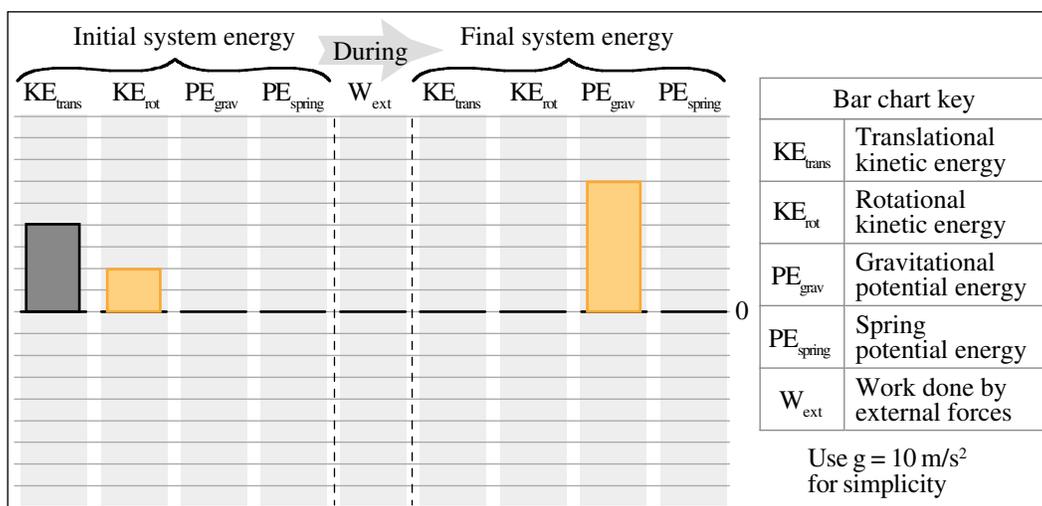
Answer: Since the disk is initially at the zero gravitational potential energy height, there is no initial potential energy. The disk is translating (its center of mass is moving) and rotating, so there are initial kinetic energies of translation and rotation. For a thin ring rolling without slipping, $I = mr^2$ and $\omega = v/r$, so $KE_{rot} = (0.5)I\omega^2 = (0.5)(mr^2)(v/r)^2 = (0.5)mv^2$. The initial rotational kinetic energy is therefore equal to the initial translational kinetic energy. In the final state, the hoop is at rest (momentarily) on the incline, so it has neither rotational nor translational kinetic energies. All of the initial system energy has been converted into gravitational potential energy.

B6-BCT28: SOLID DISK ROLLING UP A RAMP—ROTATIONAL ENERGY BAR CHART

A solid disk is initially rolling without slipping along a flat, level surface. It then rolls up an incline, coming momentarily to rest as shown.



Complete the qualitative energy bar chart below for the earth-disk system for the time between when the disk is rolling on the horizontal and when it has rolled up the ramp and is momentarily at rest. Put the zero point for the gravitational potential energy at the height of the center of the hoop when it is rolling on the horizontal surface.

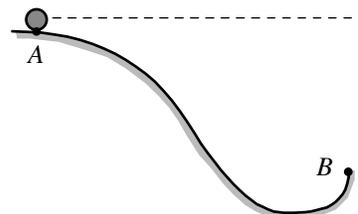


Explain your reasoning.

Answer: Since the disk is initially at the zero gravitational potential energy height, there is no initial potential energy. The disk is translating (its center of mass is moving) and rotating, so there are initial kinetic energies of translation and rotation. For a disk rolling without slipping, $I = (0.5)mr^2$ and $\omega = v/r$, so $KE_{rot} = (0.5)I\omega^2 = (0.5)((0.5)mr^2)(v/r)^2 = (0.25)mv^2$. The initial rotational kinetic energy is therefore one-half of the initial translational kinetic energy. In the final state, the hoop is at rest (momentarily) on the incline, so it has neither rotational nor translational kinetic energies. All of the initial system energy has been converted into gravitational potential energy.

B6-QRT29: SOLID SPHERE ROLLING ALONG A TRACK—LOCATION AT HIGHEST POINT

A solid sphere rolls without slipping along a track shaped as shown at right. It starts from rest at point *A* and is moving vertically when it leaves the track at point *B*.



At its highest point while in the air, will the sphere be (a) *above*, (b) *below*, or (c) *at the same height as point A*? _____

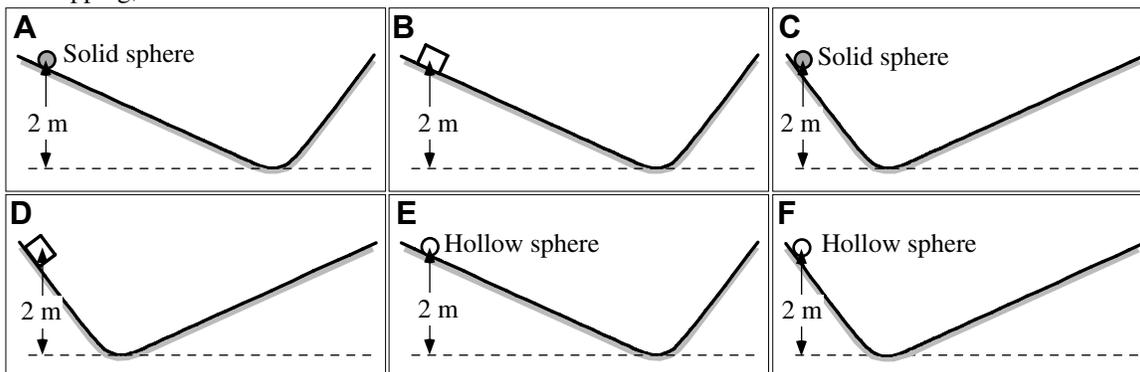
Explain your reasoning.

Answer: It will be below point A.

The initial potential energy will be converted into both rotational kinetic energy and translational kinetic energy at point B. After the ball is launched, it will still be spinning. Once it is in the air there is no external torque acting on it so it will continue to rotate at the angular velocity with which it was launched. At the top of its trajectory, it will still have rotational kinetic energy, so the final gravitational potential energy will be less than the initial.

B6-RT30: MOVING DOWN A RAMP—MAXIMUM HEIGHT ON THE OTHER SIDE OF A RAMP

In each case, a 1-kg object is released from rest on a ramp at a height of 2 m from the bottom. All of the spheres roll without slipping, and the blocks slide without friction.



Rank the maximum height of the objects on the other side of the ramp.

						OR				
1	2	3	4	5	6		All the same	All zero	Cannot determine	
Greatest						Least				

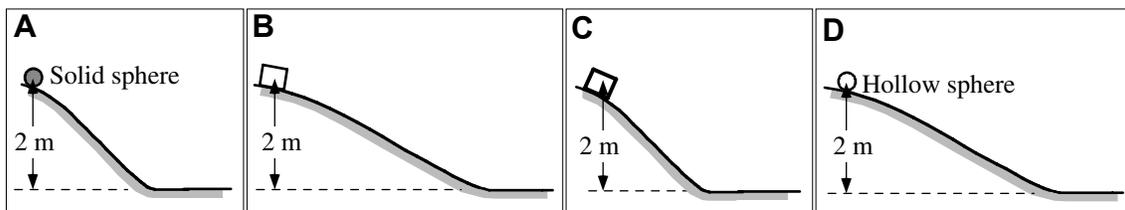
Explain your reasoning.

Answer: All the same.

None of the objects lose energy as they travel, so they will all have the same potential energy on the other side. All objects will come to rest on the other side at a height of 2 meters.

B6-RT31: OBJECTS MOVING DOWN RAMPS—SPEED AT BOTTOM

In each case, a 1-kg object is released from rest on a ramp at a height of 2 m from the bottom. All of the spheres roll without slipping, and the blocks slide without friction. The ramps are identical in Cases A and C. The ramps in Cases B and D are identical and are not as steep as the others.



Rank the speed of the objects when they reach the horizontal surface at the bottom of the ramp.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

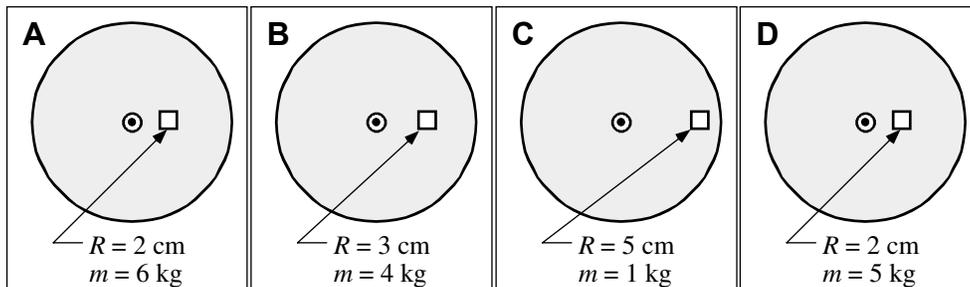
Explain your reasoning.

Answer: B = C > A > D.

Since all of the masses are the same a large translational speed corresponds to a large translational kinetic energy. At the bottom of the ramp all of the objects have converted all of their initial potential energy into kinetic energy. However the spheres will have converted some of the potential energy into rotational kinetic energy as well as translational kinetic energy, whereas all of the initial potential energy of the blocks will have been converted into translational kinetic energy. Since the height of the objects initially is all the same, all of the initial energies are the same. The shape of the ramp does not matter. Since a hollow sphere has a greater moment of inertia than a solid sphere, the hollow spheres will have a greater fraction of their energy as rotational energy when they are rolling without slipping.

B6-RT32: BLOCKS ON ROTATING DISC—HORIZONTAL FRICTIONAL FORCE

A block is placed on a rotating disc and moves in a circular path. The discs have the same rotation rate in each case, but the masses of the blocks and their distance from the center varies.



Rank the magnitude of the frictional force on blocks by the discs.

				OR			
1	2	3	4		All the same	All zero	Cannot determine
Greatest			Least				

Explain your reasoning.

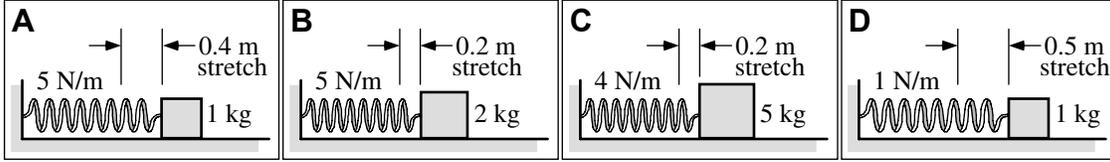
Answer: A = B > D > C.

The blocks are being held on the discs by the frictional force which in this case is acting as the centripetal force. Centripetal forces are calculated by mass times velocity squared divided by the radius. The linear velocity is the radius times the angular velocity, so the forces are proportional to the product of the mass and the radius.

B7 OSCILLATORY MOTION

B7-RT01: MASS ON HORIZONTAL SPRING SYSTEMS I—OSCILLATION FREQUENCY

A block rests on a frictionless surface and is attached to the end of a spring. The other end of the spring is attached to a wall. Four block–spring systems are considered. The springs are stretched to the right by the distances shown in the figures and then released from rest. The blocks oscillate back and forth. The mass and force constant of the spring are given for each case.



Rank the frequency of the oscillatory motion of the block.

				OR			
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

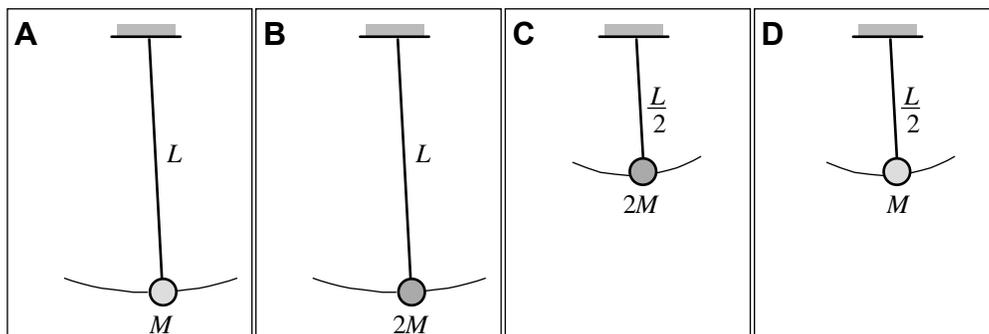
Explain your reasoning.

Answer: A > B > D > C.

Factors that affect the frequency for this system are the mass of the block and the stiffness of the spring, characterized by the spring constant. The frequency is independent of the amplitude, or maximum displacement. The frequency is proportional to the square root of the ratio of the spring constant k to the mass m , giving the specified ranking.

B7-RT02: SWINGING SIMPLE PENDULA—OSCILLATION FREQUENCY

The simple pendulum shown in Case A consists of a mass M attached to a massless string of length L . If the mass is pulled to one side a small distance and released, it will swing back and forth. Cases B, C, and D are variations of this system.



Rank the oscillation frequency of the masses.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>
1	2	3	4		All	Cannot
Greatest			Least		the same	determine

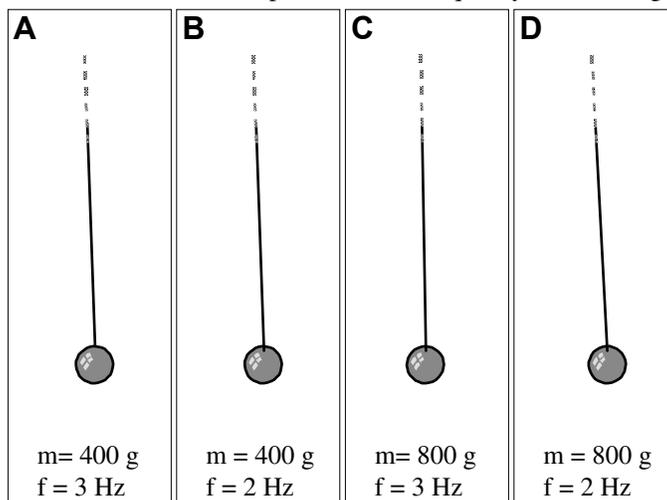
Explain your reasoning.

Answer: $C = D > A = B$.

The frequency is the inverse of the period or time for one complete swing. So the higher the frequency the smaller the time. The period is independent of the mass of the bob and depends only on the length.

B7-RT03: SWINGING SPHERE ON LONG STRINGS—TIME FOR ONE SWING

Metal spheres are hung on the ends of long strings. The spheres have been pulled to the side and released so that they are swinging back and forth. The mass of the sphere and the frequency of the swing are given in each case.



Rank the time it takes to make one complete swing.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

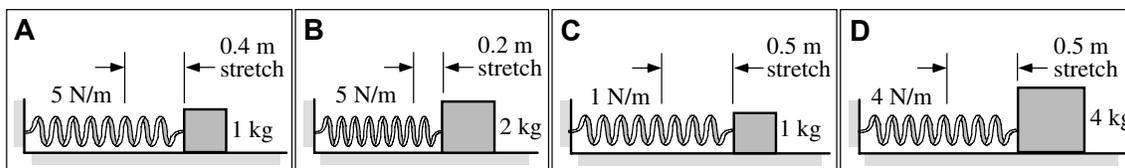
Explain your reasoning.

Answer: B = D > A = C.

The frequency is the inverse of the period or time for one complete swing. So the higher the frequency the smaller the time. The period is independent of the mass of the bob.

B7-RT04: MASS ON HORIZONTAL SPRING SYSTEMS II—PERIOD OF OSCILLATING MASS

A block rests on a frictionless surface and is attached to the end of a spring. The other end of the spring is attached to a wall. Four block–spring systems are considered. The springs are stretched to the right by the distances shown in the figures and then released from rest. The blocks oscillate back and forth. The mass and force constant of the spring are given for each case.



Rank the period (the time it takes the block to complete one cycle) of the oscillatory motion of the block.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

Explain your reasoning.

Answer: C = D > B > A.

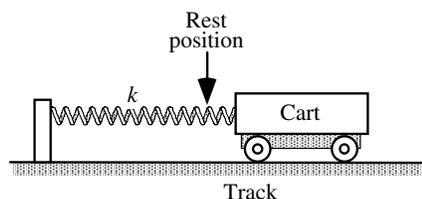
The period is given by the square root of the mass divided by the spring constant. The period is independent of the amplitude.

B7-QRT05: POSITION-TIME GRAPH OF A CART ATTACHED TO A SPRING—MASS AND PERIOD

A frictionless cart of mass m is attached to a spring with spring constant k . When the cart is displaced from its rest position and released, it oscillates with a period τ that is given by

$$\tau = 2\pi\sqrt{m/k}$$

The graph of the position of this cart as a function of time is labeled Experiment A. Graphs for two other experiments that use different masses are shown below this. The same spring is used in all three experiments.

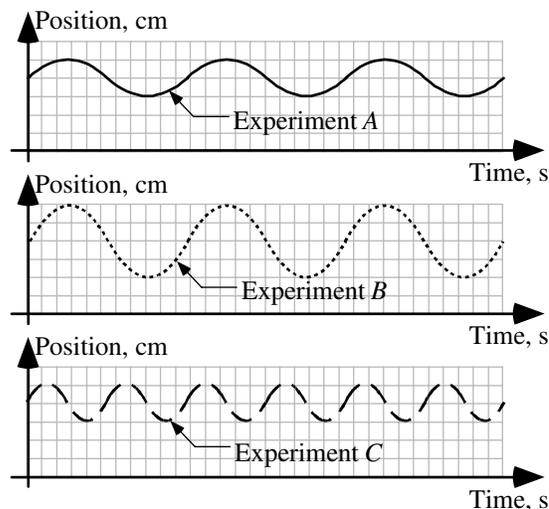


(a) Compared to Experiment A, in Experiment B the cart has

- (i) *twice* as much mass.
- (ii) *four times* as much mass.
- (iii) *one-half* the mass.
- (iv) *one-fourth* the mass.
- (v) *the same* mass.

Explain your reasoning.

Answer: (v) The cart has the same mass. The periods of the systems in the two experiments are the same, so the masses have to be the same also.



(b) Compared to Experiment A, in Experiment C the cart has

- (i) *twice* as much mass.
- (ii) *four times* as much mass.
- (iii) *one-half* the mass.
- (iv) *one-fourth* the mass.
- (v) *the same* mass.

Explain your reasoning.

Answer: (iv) The cart has one-fourth the mass. The period of experiment C is half that of experiment A, so the mass is less for experiment C. Since the period is proportional to the square root of the mass, the mass in C has to be one-fourth that of A.

(c) Suppose that in a fourth experiment (Experiment D), the mass used in Experiment A was doubled and the spring was replaced with a spring with spring constant $2k$. The period in Experiment D would be

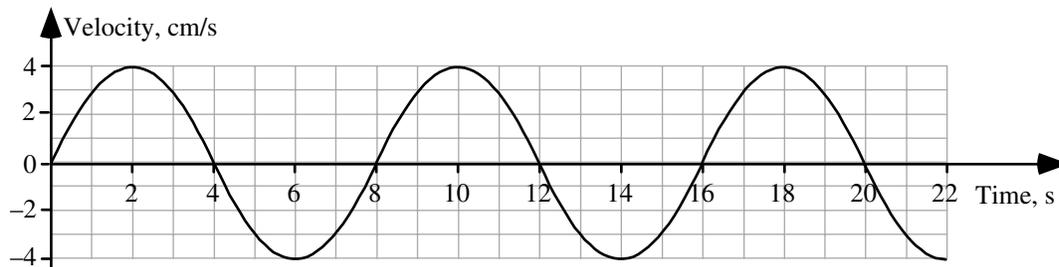
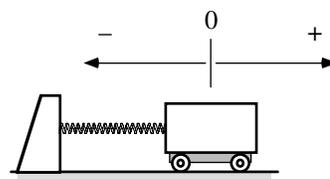
- (i) *the same* as the period in Experiment A.
- (ii) *double* the period in Experiment A.
- (iii) *four times* the period in Experiment A.
- (iv) *one-half* the period in Experiment A.
- (v) *one-fourth* the period in Experiment A.

Explain your reasoning.

Answer: (i) The period would be the same in experiment D as it was in experiment A. Since the period is determined by the square root of the mass divided by the spring constant, doubling both will not change the period.

B7-CRT06: VELOCITY-TIME GRAPH—FREQUENCY AND PERIOD

A cart attached to a spring is displaced from equilibrium and then released. There is no friction. A graph of velocity as a function of time for the cart is shown. The arrows and signs above the cart indicate the positive and negative directions for the position of the cart.



(a) What is the period of the motion for this cart?

Explain your reasoning.

Answer: 8 seconds.

The period is the time for the complete cycle of the oscillation so we measure along the horizontal, time, axis from the same point—peak to peak, or trough to trough, etc—on two successive cycles..

(b) What is the frequency of the motion for this cart?

Explain your reasoning.

Answer: 1/8 Hz.

The period is 8 seconds from the graph. The frequency is the reciprocal of the period or 1/8 Hz.

(c) In which direction was the cart displaced from equilibrium before it was released?

Explain your reasoning.

Answer: Since the velocity just after the cart was released is positive, the cart must be moving toward the right. It was displaced to the left.

B7-SCT07: MASS ON A VERTICAL SPRING—ACCELERATION

A mass is oscillating up and down at the end of a spring. Three students are discussing the acceleration of the mass:

Aileen: *“I think the acceleration of the mass will be largest when it is at the end of its oscillations turning around. That’s where the spring is stretched the most.”*

Brigitte: *“No, I don’t see how that can be. Its velocity is zero at that point, so its acceleration has to be zero also.”*

Chandra: *“I disagree. The acceleration is largest when the mass is halfway between the middle and the end because that is where its speed is changing the most.”*

With which, if any, of these students do you agree?

Aileen _____ Brigitte _____ Chandra _____ None of them _____

Explain your reasoning.

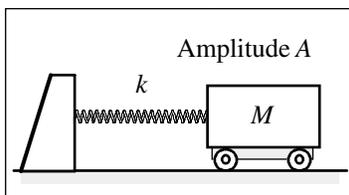
Answer: Aileen is correct.

Since maximum displacement is the point where the spring is stretched, or compressed, the most the force exerted by the spring has to be largest there.



B7-LMCT08: MASS CONNECTED TO A HORIZONTAL SPRING—FREQUENCY

A mass-spring system consists of a spring with a spring constant (or stiffness) k and unstretched length L , connected to a cart of mass M resting on a horizontal frictionless surface as shown. If the cart is pulled to one side a small distance and released, it will oscillate back and forth with amplitude A and frequency f .



Identify from choices (i)–(iv) how each change described below will affect the frequency of the oscillating mass-spring system.

Compared to the case above, this change will:

- (i) *increase* the frequency of the system.
- (ii) *decrease* the frequency of the system.
- (iii) *have no effect* on the frequency of the system.
- (iv) *have an indeterminate* effect on the frequency of the system.

Each of these modifications is the only change to the initial situation described above.

(a) The mass is increased. _____

Explain your reasoning.

Answer: (ii). The frequency is proportional to the square root of k/m and independent of the amplitude.

(b) The spring constant or stiffness is increased. _____

Explain your reasoning.

Answer: (i) The frequency is proportional to the square root of k/m .

(c) The mass is pulled a little farther and then released. _____

Explain your reasoning.

Answer: (iii) The frequency is independent of the amplitude.

(d) The spring constant is doubled to $2k$ and the mass is reduced to $M/2$. _____

Explain your reasoning.

Answer: (i) The frequency is proportional to the square root of k/m so both changes increase the frequency.

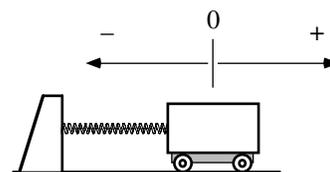
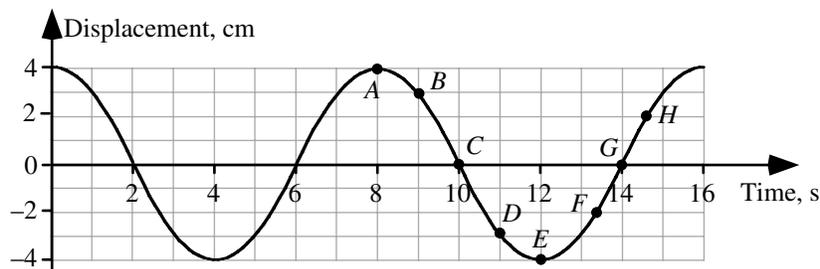
(e) The amplitude is increased and the mass is increased. _____

Explain your reasoning.

Answer: (ii) The frequency is proportional to the square root of k/m and independent of the amplitude.

B7-QRT09: OSCILLATION DISPLACEMENT-TIME GRAPH—KINEMATIC QUANTITIES

A cart attached to a spring is displaced from equilibrium and then released. There is no friction. A graph of displacement as a function of time for the cart is shown. The arrows and signs above the cart indicate the positive and negative directions for the position of the cart.



For each question below, choose from the labeled points above, or state “none.”

(a) At which point or points is the acceleration positive? _____

Explain your reasoning.

Answer: Points D, E, and F.

The acceleration is positive when the velocity is positive and increasing, or when the velocity is negative and decreasing. The velocity at point D is negative (the slope of the position graph is negative) and decreasing (the magnitude of the slope is smaller just after point D than it is just before point D); at point F the velocity is positive and increasing; and at point E the slope of the graph is instantaneously zero, but the slope is negative just before and positive just after, so the acceleration is positive.

(b) At which point or points does the cart have zero velocity but nonzero net force? _____

Explain your reasoning.

Answer: Points A and E.

Since the slope, and consequently the velocity, is zero at these points, but the velocity is changing, there is an acceleration, and therefore a net force.

(c) At which point or points is the net force on the cart equal to zero? _____

Explain your reasoning.

Answer: Points C and G.

At these points the slope of the position graph is constant, so the velocity is constant. The acceleration is therefore zero, and the net force must be zero. From a dynamics perspective, at these points the cart is passing through the equilibrium position, and the spring exerts no force.

(d) At which point or points are the acceleration, velocity, and displacement all positive? _____

Explain your reasoning.

Answer: None.

The force on the cart is always acting toward the equilibrium position; so the acceleration is negative when the displacement is positive, and positive when the displacement is negative.

(e) At which point or points is the acceleration nonzero and opposite in sign to the position? _____

Explain your reasoning.

Answer: A, B, D, E, F, H.

The acceleration is always opposite in sign to the position.

(f) At which point or points is the velocity nonzero and opposite in sign to the acceleration? _____

Explain your reasoning.

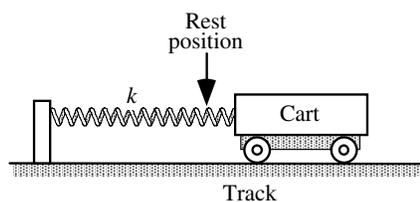
Answer: Points D and H.

Whenever the cart is slowing down, the velocity and acceleration are in opposite directions.

B7-SCT10: HORIZONTAL OSCILLATING CART—PERIOD

A frictionless cart of mass M is attached to a spring with spring constant k . When the cart is displaced 6 cm from its rest position and released, it oscillates with a period of 2 seconds.

Four students are discussing what would happen to the period of oscillation if the original cart with mass M was displaced 12 cm from its rest position instead of 6 cm and again released:



Adan: “Since the spring is stretched more, the force will be greater, causing a greater acceleration and greater speeds overall. Since the cart is moving faster, the time will go down, probably to 1 second since the force is doubled.”

Barb: “The cart has farther to go now, and so it’s going to take longer to make a complete cycle. It’s going to go farther on both sides of the rest position, so the round-trip is 48 cm instead of 24 cm. The period is going to double.”

Charles: “The cart has four times as much energy, and the conjugate variable for energy is time according to the Heisenberg uncertainty principle. The energy quadruples when the spring stretch is doubled, and so the time must be only one-quarter as much. The period will be one-half second.”

Dallas: “Stretching the spring twice as far means that k is twice as big. And the period is 2π times the square root of the spring constant divided by the mass. Doubling the spring constant and leaving the mass alone is going to double what’s inside the square root, and after we take the square root we get a period of 2 seconds times the square root of 2, or 1.414 seconds.”

With which, if any, of these students do you agree?

Adan _____ Barb _____ Charles _____ Dallas _____ None of them _____

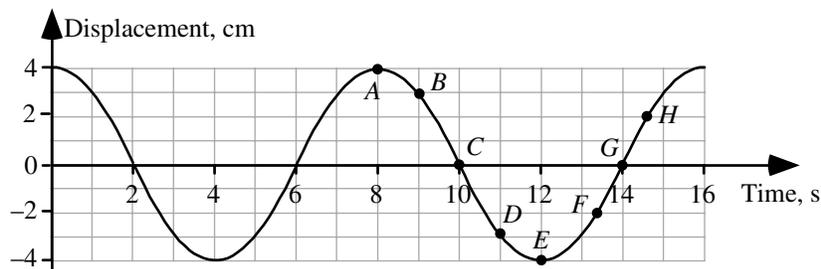
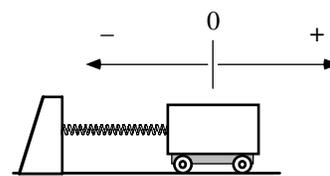
Explain your reasoning.

Answer: None of the them.

The period of oscillation is independent of the amplitude for small oscillations. We can see that this makes sense if we think about the fact that increasing the amplitude means the cart travels a longer distance each period, but since the maximum force also increases the average speed is larger. In this case the two effects offset each other.

B7-QRT11: OSCILLATING MASS ON SPRING DISPLACEMENT-TIME GRAPH—DIRECTIONS

A cart attached to a spring is displaced from equilibrium and then released. A graph of displacement as a function of time for the cart is shown. There is no friction. Points are labeled A–H in the graph. The arrows and signs above the cart indicate the positive and negative directions for the displacement of the cart.



For each labeled point above, identify if the vector quantity listed below is in the positive (+) direction, negative (-) direction, or is zero (0) for no direction.

Point	Acceleration	Velocity	Displacement	Net Force
A	-	0	+	-
B	-	-	+	-
C	0	-	0	0
D	+	-	-	+
E	+	0	-	+
F	+	+	-	+
G	0	+	0	0
H	-	+	+	-

Explain your reasoning.

Answer: The signs for the displacement can be read from the graph. The velocity is related to the slope of the graph at these points. The force exerted by a spring is always directed opposite to the displacement from equilibrium. In this case, the spring force is the net force and the acceleration has the same direction as the net force.

B7-SCT12: MASS OSCILLATING ON A VERTICAL SPRING—ENERGY

A mass hanging on a vertical spring is pulled down a distance d and released. The mass undergoes simple harmonic motion. Three physics students make the following contentions about this situation:

Alexandra: “The maximum kinetic energy of this mass-spring system is fixed by the properties of the system and does not depend on how far down the mass is pulled. How far the mass is pulled will only affect the frequency of the oscillations.”

Bruno: “No, that can’t be right since increasing the amplitude, or how far down it is pulled, increases the potential energy of the system. I don’t think the amplitude has any effect on the frequency.”

Chung: “I agree in part with both of you. I think the amplitude does affect the maximum kinetic energy, but I also think it affects the frequency of the oscillations.”



With which, if any, of these students do you agree?

Alexandra _____ Bruno _____ Chung _____ None of them _____

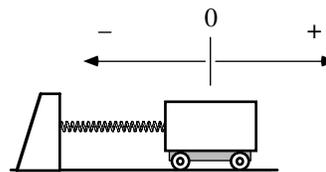
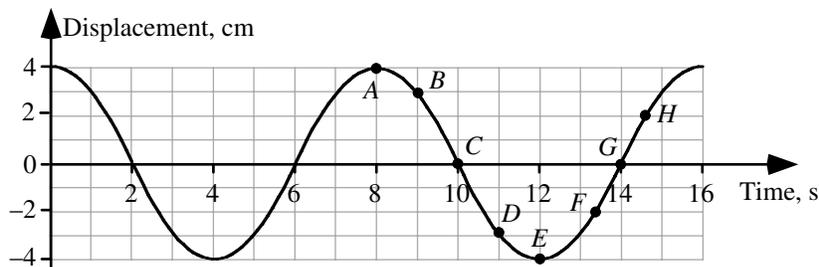
Explain your reasoning.

Answer: Bruno is correct.

The maximum spring potential energy is proportional to the amplitude and the maximum spring potential energy is equal to the maximum kinetic energy. So increasing the amplitude will also increase the maximum speed and for simple harmonic motion the result is that the amplitude and frequency are unrelated.

B7-QRT13: DISPLACEMENT-TIME GRAPH—ENERGY QUANTITIES

A cart attached to a spring is displaced from equilibrium and then released. A graph of displacement as a function of time for the cart is shown. There is no friction. Points are labeled A–H in the graph.



For each question below, choose from the labeled points above or state “none” for the mass-spring-earth system.

(a) At which point or points are the spring potential energy and the cart’s kinetic energy both at their maximum values? _____

Explain your reasoning.

None.

The spring potential energy and the cart’s kinetic energy always add up to the total energy, which is constant. So if one is at a maximum value, the other is at a minimum value.

(b) At which point or points is the kinetic energy equal to zero? _____

Explain your reasoning.

Points A and E.

The slope of the graph is zero at these points indicating zero velocity.

(c) At which point or points is the total energy at its maximum value? _____

Explain your reasoning.

A, B, C, D, E, F, G, and H.

The total energy is always the same.

(d) At which point or points is the spring potential energy negative? _____

Explain your reasoning.

None. The spring potential energy is proportional to the square of the distance the spring is stretched or compressed, and is always positive or zero.

(e) At which point or points is the kinetic energy positive? _____

Explain your reasoning.

Points B, C, D, F, G and H.

The kinetic energy is always either positive or zero.

(f) At which point or points is the kinetic energy at its maximum value and the spring potential energy at its minimum value? _____

Explain your reasoning.

Points C and G.

When the cart is in the equilibrium position the spring is unstretched and there is no spring potential energy. At these points the kinetic energy of the cart is equal to the total energy.

(g) At which point or points is the kinetic energy at its minimum value and the spring potential energy at its maximum value? _____

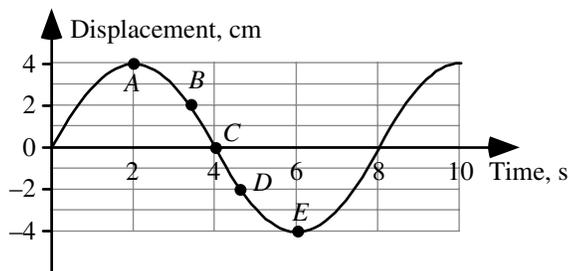
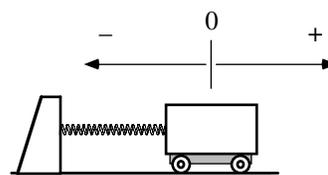
Explain your reasoning.

Points A and E.

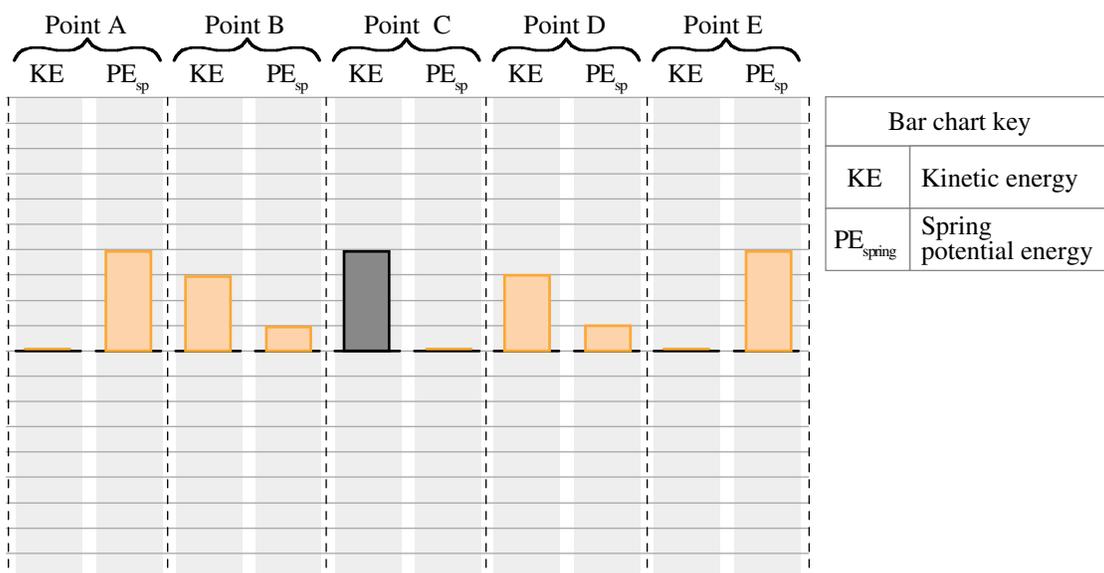
When the cart is at its maximum displacement the cart is momentarily at rest and the kinetic energy is zero.

B7-BCT14: OSCILLATING MASS ON SPRING DISPLACEMENT-TIME GRAPH—ENERGY

A cart attached to a spring is given an initial push, displacing it from its equilibrium position. A graph of displacement as a function of time for the cart is shown at right. The system has a total initial energy of 12 J and there is no friction. Five points are labeled A–E in the graph.



For each labeled point, complete the bar chart below for the kinetic energy and the potential energy for the cart-spring system.



Explain your reasoning.

Answer: The total energy of the cart-spring system is constant so points A and E have four bars of potential energy and no kinetic. For points B and D the kinetic energy will be three bars and the potential energy will be one bar.