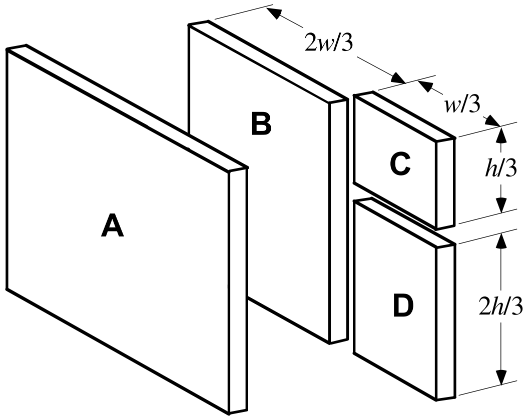
INSTRUCTORS MANUAL SECTION C

C1 DENSITY

C1-RT01: CUTTING UP A BLOCK—DENSITY

A block of material (labeled A in the diagram) with a width w, height h, and thickness t has a mass of M_o distributed uniformly throughout its volume. The block is then cut into three pieces, B, C, and D, as shown.



Rank the density of the original block A, piece B, piece C, and piece D.

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

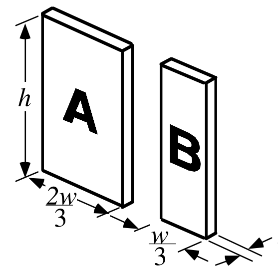
Explain your reasoning.

Answer: The density is the same for all four pieces.

Since the mass is uniformly distributed, a piece with half the volume will also have half the mass but the density, the ratio of mass to volume, remains the same.

C1-SCT02: BREAKING UP A BLOCK—DENSITY

A block of material with a width w, height h, and thickness t has a mass of M_o distributed uniformly throughout its volume. The block is then broken into two pieces, A and B, as shown. Three students make the following statements:



Ajay: *"They both have the same density. It's still the same material."*

Ben: *"The density is the mass divided by the volume, and the volume of B is smaller. Since the mass is uniform and the volume is in the denominator, the density is larger for B."*

Chithra: *"The density of piece A is larger than the density of piece B since A is larger; thus it has more mass."*

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

Ajay _____ Ben _____ Chithra _____ None of them_____

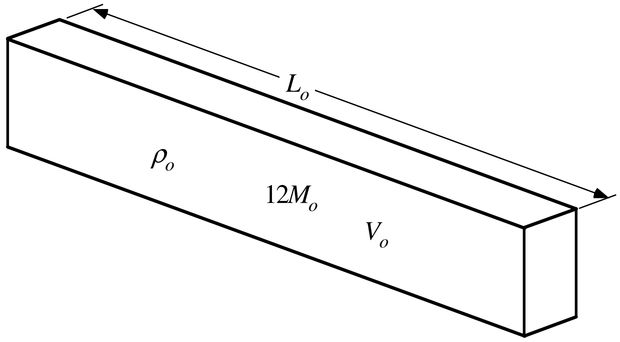
Explain your reasoning.

Answer: Ajay is correct.

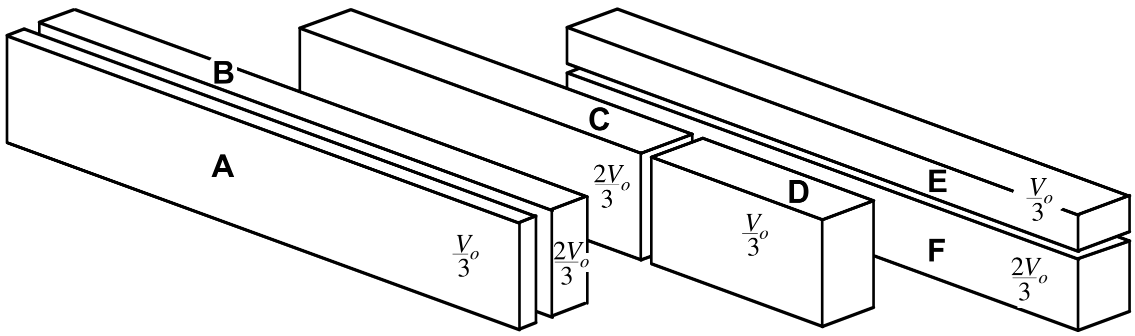
Density is the ratio of mass to volume. The larger piece has twice the mass but also twice the volume of the smaller piece. Therefore the ratio of mass to volume is the same for both and the same as the density of the unbroken block.

C1-QRT03: SLICING UP A BLOCK—MASS AND DENSITY

The plastic block shown below has a volume V_o and a mass $12M_o$ distributed evenly to give a uniform density ρ_o.



Three possible ways to slice the plastic block into unequal pieces are shown below. In each case, the larger piece has a volume $2V_o/3$ and the smaller piece has a volume $V_o/3$.



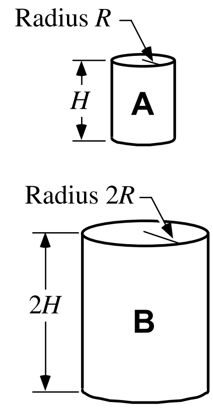
Fill in the table for the mass (in terms of M_o) and density (in terms of ρ_o) of the pieces of the block labeled A– F.

	Mass	Density
Original block	$12M_o$	ρ_o
Piece A	$4M_o$	ρ_o
Piece B	$8M_o$	ρ_o
Piece C	$8M_o$	ρ_o
Piece D	$4M_o$	ρ_o
Piece E	$4M_o$	ρ_o
Piece F	$8M_o$	ρ_o

Answer: Since the density is uniform, the masses of the pieces will be proportional to the volumes of the pieces, so one-third of the block by volume will also be one-third by mass. The density is the ratio of mass to volume, and will not depend on the size of the piece.

C1-QRT04: CYLINDERS WITH THE SAME MASS I—VOLUME, AREA, AND DENSITY

Two solid cylinders are shown. Cylinder A has a height H and a radius R, and cylinder B has a height $2H$ and a radius $2R$. Both cylinders have uniform densities and the same mass. Cylinder A has a density ρ_A and volume V_A.



If r is the radius of a cylinder and h is the height, then the volume of the cylinder is $V = \pi r^2 h$, and the surface area is $SA = 2\pi r^2 + 2\pi rh$.

(a) What is the volume of cylinder B in terms of the volume of cylinder A? (Your answer should look like $V_B = n\ V_A$, where n is some number.)

Explain your reasoning.

Answere: The volume of cylinder B = 8 times the volume of cylinder A since the volume is proportional to the product of the cross-sectional area (which is proportional to the square of the radius) and the height of the cylinder, and the radius and the height have each doubled.

(b) What is the surface area of cylinder B in terms of the surface area of cylinder A? (Your answer should look like $SA_B = n\ SA_A$, where n is some number.)

Explain your reasoning.

Answer: The surface area of B = 4 surface area of A.
The surface of each cylinder is made up of the circles at the top and bottom and the 'side wall.' The top and bottom of the cylinder are circles, and the area of a circle is proportional to the square of the radius. Since the radius is twice as big for cylinder B as for cylinder A, the area of the top and bottom is 4 times as big for cylinder B. The 'side wall' of the cylinder has an area equal to the circumference times the height, and the circumference of a circle is proportional to the radius. Since both height and radius have doubled, the area of the sidewall has also quadrupled. The overall surface area is 4 times as large for cylinder B as for cylinder A.

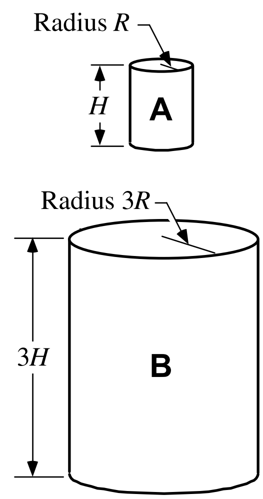
(c) What is the density of cylinder B in terms of the density of cylinder A? (Your answer should look like $\rho_B = n\ \rho_A$, where n is some number.)

Explain your reasoning.

Answer: $_B = \rho_A/8$
Since B has 8 times the volume of A with the same total mass, its density will be one-eighth that of A.

C1-QRT05: CYLINDERS WITH THE SAME MASS II—VOLUME, AREA, AND DENSITY

Two solid cylinders are shown. Cylinder A has a height H and a radius R and cylinder B has a height $3H$ and a radius $3R$. Both cylinders have uniform densities and the same mass. Cylinder A has a density ρ_A and volume V_A.



If r is the radius of a cylinder and h is the height, then the volume of the cylinder is $V = \pi r^2 h$, and the surface area is $SA = 2\pi r^2 + 2\pi rh$.

(a) What is the volume of cylinder B in terms of the volume of cylinder A? (Your answer should look like $V_B = n\ V_A$, where n is some number.)

Explain your reasoning.

Answer: The volume of cylinder B = 27 times the volume of cylinder A since the volume is proportional to the product of the cross-sectional area (which is proportional to the square of the radius) and the height of the cylinder, and the radius and the height have each tripled.

(b) What is the surface area of cylinder B in terms of the surface area of cylinder A? (Your answer should look like $SA_B = n\ SA_A$, where n is some number.)

Explain your reasoning.

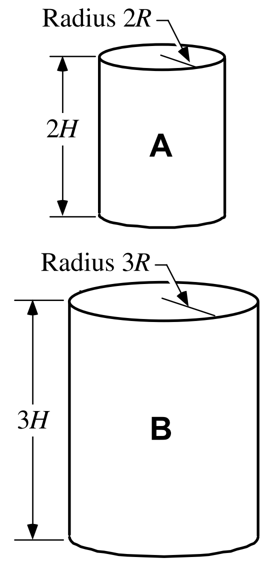
Answer: The surface area of B = 9 surface area of A.
The surface of each cylinder is made up of the circles at the top and bottom and the 'side wall.' The top and bottom of the cylinder are circles, and the area of a circle is proportional to the square of the radius. Since the radius is three times as big for cylinder B as for cylinder A, the area of the top and bottom is 9 times as big for cylinder B. The 'side wall' of the cylinder has an area equal to the circumference times the height, and the circumference of a circle is proportional to the radius. Since both height and radius have tripled, the area of the sidewall has also increased by a factor of 9. The overall surface area is 9 times as large for cylinder B as for cylinder A.

(c) What is the density of cylinder B in terms of the density of cylinder A? (Your answer should look like $\rho_B = n\ \rho_A$, where n is some number.)

Explain your reasoning.

Answer: $_B = \rho_A/27$
Since B has 27 times the volume of A with the same total mass, its density will be one-eighth that of A.

C1-QRT06: Cylinders with the Same Mass III—Volume, Area, and Density



Two solid cylinders are shown. Cylinder A has a height $2H$ and a radius $2R$ and cylinder B has a height $3H$ and a radius $3R$. Both cylinders have uniform densities and the same mass. Cylinder A has a density ρ_A and volume V_A.

If r is the radius of a cylinder and h is the height, then the volume of the cylinder is $V = \pi r^2 h$, and the surface area is $SA = 2\pi r^2 + 2\pi rh$.

(a) What is the volume of cylinder B in terms of the volume of cylinder A? (Your answer should look like $V_B = n\ V_A$, where n is some number.)

Explain your reasoning.

The volume of cylinder B = 27/8 times the volume of cylinder A since the volume is proportional to the product of the cross-sectional area (which is proportional to the square of the radius)and the height of the cylinder. Cylinder B is 1.5 times as large in every dimension as cylinder A, or 3/2 as large. The volume of cylinder B is therefore (3/2)(3/2)(3/2) = 27/8 times as large as the volume of cylinder A.

(b) What is the surface area of cylinder B in terms of the surface area of cylinder A? (Your answer should look like $SA_B = n\ SA_A$, where n is some number.)

Explain your reasoning.

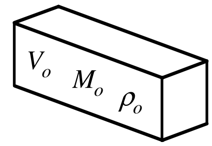
Answer: The surface area of B = 9/4 surface area of A.
The surface of each cylinder is made up of the circles at the top and bottom and the 'side wall.' The top and bottom of the cylinder are circles, and the area of a circle is proportional to the square of the radiu s. Since the radius is 1.5 times (3/2) as big for cylinder B as for cylinder A, the area of the top and bottom is (3/2)(3/2) = 9/4 times as big for cylinder B. The 'side wall' of the cylinder has an area equal to the circumference times the height, and the circumference of a circle is proportional to the radius. Since both height and radius have increased by a factor of 3/2, the area of the sidewall has also increased by a factor of 9/4. The overall surface area is 9/4 times as large for cylinder B as for cylinder A.

(c) What is the density of cylinder B in terms of the density of cylinder A? (Your answer should look like $\rho_B = n\ \rho_A$, where n is some number.)

Explain your reasoning.

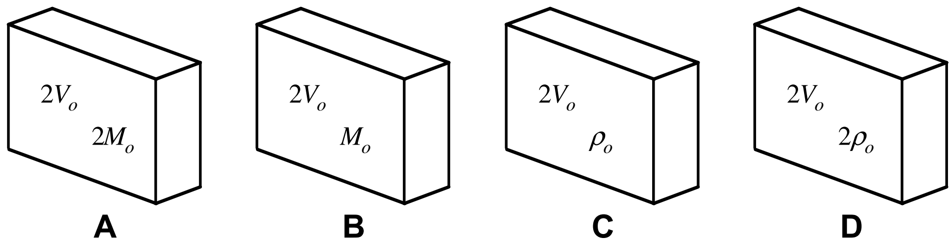
Answer: $\ _B = (8/27)\rho_A$
Since B has 27/8 times the volume of A with the same total mass, its density will be 8/27 that of A.

C1-BCT07: Four Blocks—Mass and Density

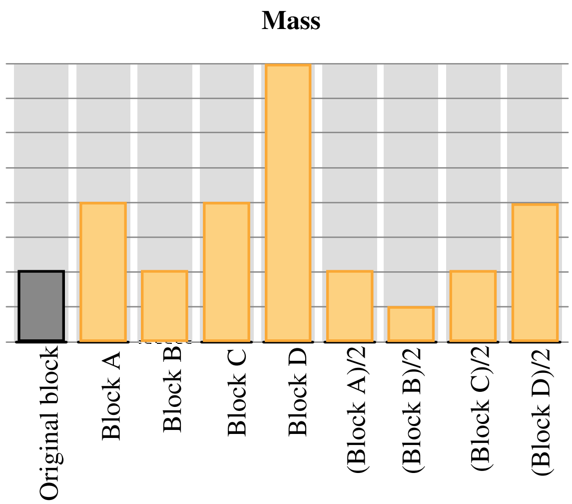


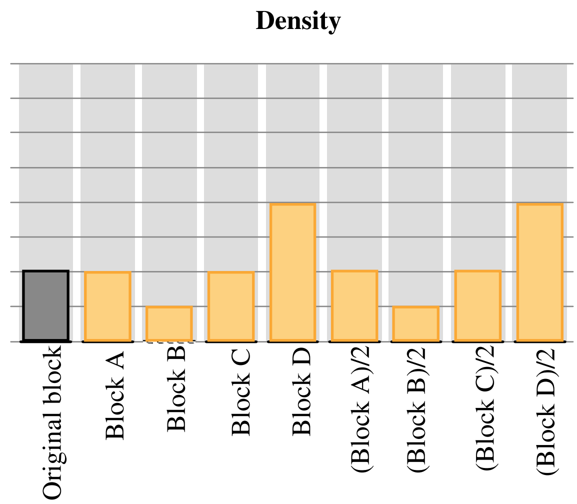
The block of material shown to the right has a volume V_o. An overall mass M_o is distributed evenly throughout the volume of the block so that the block has a uniform density ρ_o.

For each block shown below, the volume is given as well as *either* the mass or the density of the block.



Construct bar charts for the mass and density for the four blocks labeled A–D, and for the pieces of the blocks if they were cut in half labeled A/2–D/2. The mass and density for the original block are shown to set the scale of the chart.



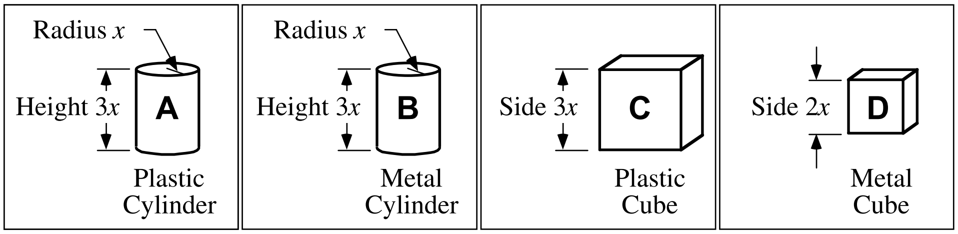


Explain your reasoning.

Answer: The masses of blocks A and B are given. The mass of block C must be $2M_o$, since it has the same density as the original block and twice the volume. The mass of block D must be 4 times the mass of the original block, since it has twice the volume and twice the density and mass is volume times density. The mass of one-half of a block will be half the mass of the full block. The density of one-half of a block will be the same as the density of a full block, since the volume is halved as well as the mass, and the density is the ratio of these quantities.

C1-RT08: Cylinders and Cubes—Density

A cylinder and a cube are carved out of a piece of plastic with uniform density, and a second cylinder and cube are carved out of a piece of metal with uniform density. Dimensions are given for the cylinders and cubes. The mass of the cylinder in Case B is twice the mass of the cylinder in Case A.



Rank the densities of the objects.

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

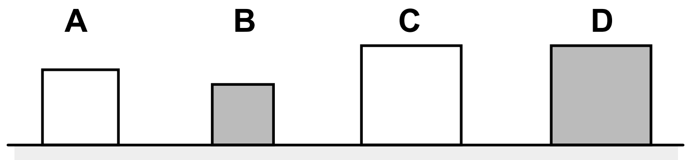
Explain your reasoning.

Answer: B = D > A = C.

The volumes of the cylinders in cases A and B are the same since they have the same dimensions, but the metal cylinder has more mass than the plastic cylinder. The density of the metal must therefore be greater than the density of the plastic. The density of both plastic pieces will be the same, since they were carved out of the same material with uniform density, and the density of both metal pieces will be the same, since they were also carved out of the same material with uniform density.

C1-QRT09: FOUR CUBES—MASS

Of the four cubes shown below, white cubes A and C are made of the same material, and gray cubes B and D are made of the same material. Each cube has a uniform density. The ranking of cube size is C = D > A > B. Cubes A and B have the same mass.



Is the mass of cube C (i) *greater than*, (ii) *less than*, or (iii) *equal to* the mass of cube D?

Explain your reasoning.

Answer: (ii) less than.

Since A and B have the same mass but B has the smaller volume, it has to have the larger density. So for equal volumes of the two materials—C and D—the gray material will have the larger mass.

C1-WWT10: POURING LIQUID BETWEEN BEAKERS—DENSITY

A liquid in a tall, narrow cylindrical beaker is poured into a wider cylindrical beaker. The liquid only fills the wider beaker to one-fourth its height in the tall beaker. A student makes the following statement:

"When the liquid was poured from the narrow beaker into the wider one, the volume changed. Since no liquid was spilled, all of the liquid is still in the wider beaker, so the density of the liquid must have changed."

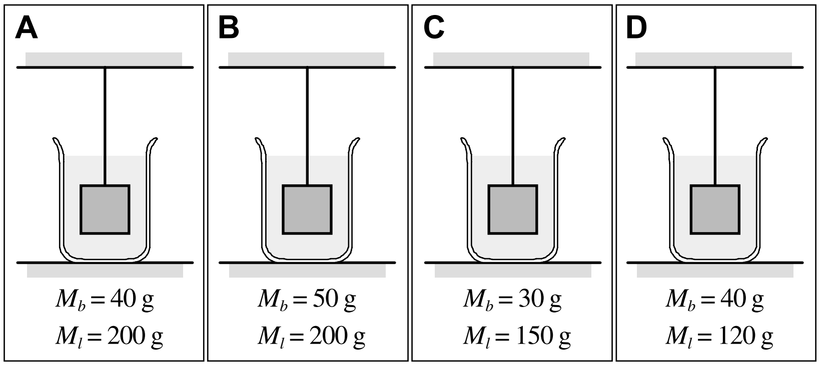
What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

Answer: The student's claim of the volume changing is wrong. All of the same liquid is still present so the mass, volume, nor density have changed.

C2 FLUIDS

C2-RT01: BLOCKS SUSPENDED IN LIQUIDS—BUOYANT FORCE

In each case, a block hanging from a string is suspended in a liquid. All of the blocks are the same size, but they have different masses (labeled M_b) because they are made of different materials. All of the containers have the same volume of liquid, but the masses of these liquids vary (labeled M_l) since the liquids are different. The volume of the blocks is one-sixth the volume of the liquids.



Rank the buoyant forces on the blocks.

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

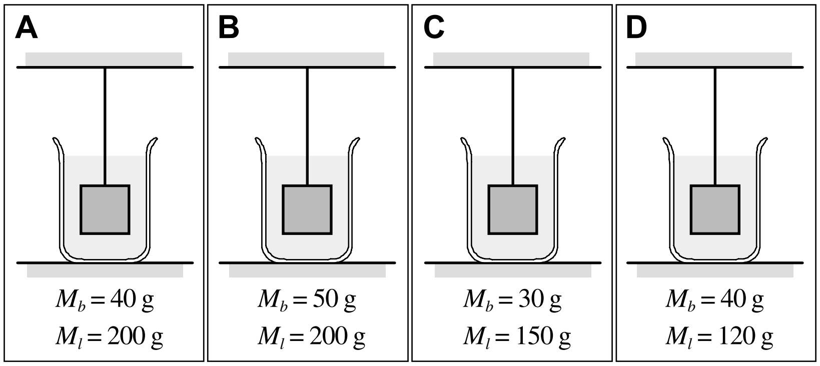
Explain your reasoning.

Answer: A = B > C > D.

The buoyant force depends on the weight of the displaced liquid. Since all the blocks are the same size and therefore displace the same volume of liquid, the weight of the displaced liquid is proportional to the density of the displaced liquid. All of the liquids have the same volume, so the density of the liquid is proportional to the mass of the liquid.

C2-RT02: BLOCKS SUSPENDED IN LIQUIDS—VOLUME OF LIQUID DISPLACED

In each case, a block hanging from a string is suspended in a liquid. All of the blocks are the same size, but they have different masses (labeled M_b) because they are made of different materials. All of the containers have the same volume of liquid, but the masses of these liquids vary (labeled M_l) since the liquids are different. The volume of the blocks is one-sixth the volume of the liquids.



Rank the volume of the liquid displaced by the blocks.

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

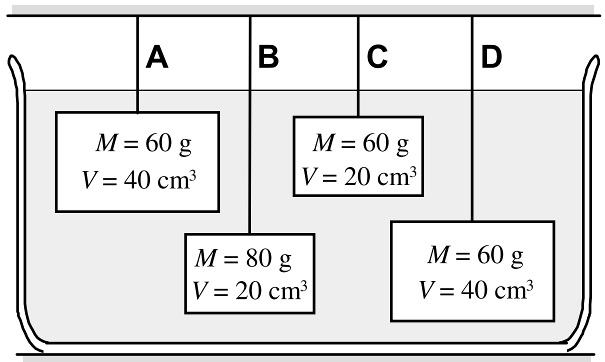
Explain your reasoning.

Answer: All the same.

Since all of the blocks are the same size and all are fully immersed, they will all displace their volume.

C2-RT03: BLOCKS SUSPENDED IN WATER AT DIFFERENT DEPTHS—BUOYANT FORCE

Blocks that have different masses and volumes are suspended by strings in water. The blocks are at two different depths below the surface as shown.



Rank the buoyant force exerted on the blocks by the water.

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

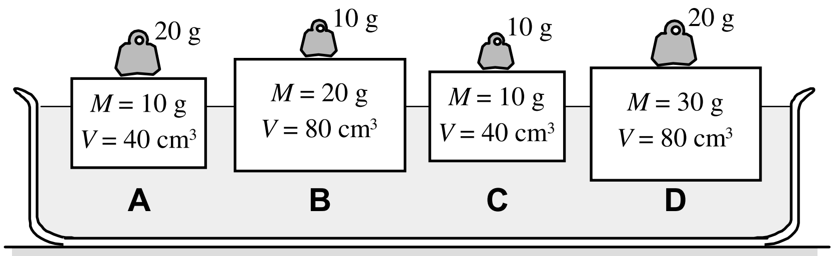
Explain your reasoning.

Answer: A = D > B = C.

The buoyant force is equal to the weight of the liquid displaced which is given by the volume of the liquid displaced—equal to the volumes of the blocks here—times the density of the liquid times the acceleration due to gravity. Since all blocks are immersed in the same liquid, the buoyant force is proportional to the volume of the blocks.

C2-RT04: Floating Blocks with Different Loads—Buoyant Force

Wood blocks that have different masses and different volumes are floating in water. On top of these blocks are additional masses as shown.



Rank the buoyant force exerted by the water on the wood blocks.

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

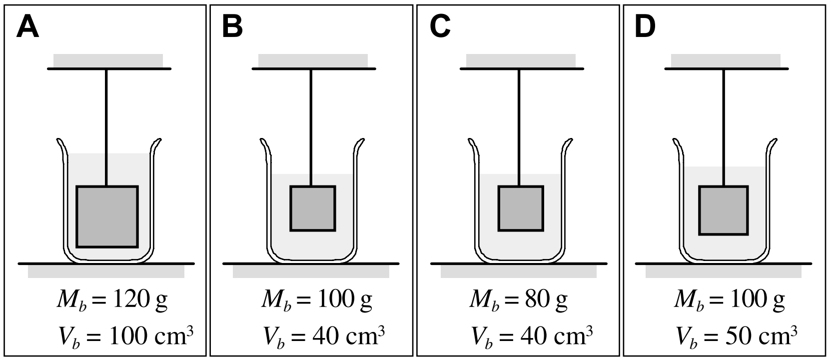
Explain your reasoning.

Answer: D > A = B > C.

Since these block-mass systems all float in the water the buoyant forces have to be equal to the weights of the systems.

C2-RT05: Blocks Suspended in Liquids—Buoyant Force

In each case, a block hanging from a string is suspended in a liquid. The blocks are made of different materials and vary in mass and volume as shown. All of the containers have the same volume of an identical liquid.



Rank the buoyant force exerted by the liquid on the blocks.

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

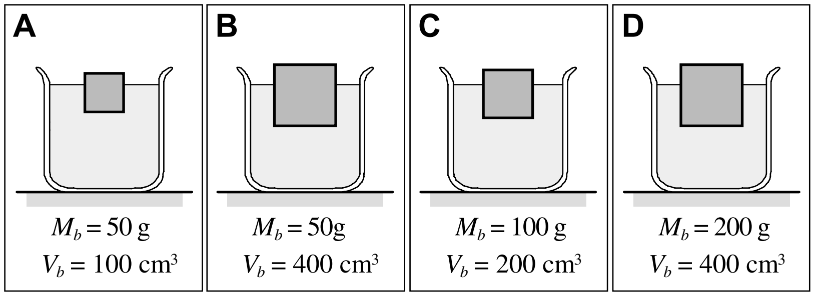
Explain your reasoning.

Answer: A > D > B = C.

Since these blocks are all fully immersed in the same liquid the buoyant forces will be determined by the volumes of the blocks because that will also be the volume, and mass, of the liquid displaced.

C2-RT06: BLOCKS FLOATING IN LIQUIDS—BUOYANT FORCE

In each case, a block floats in a liquid. The blocks are made of different materials and vary in mass and volume as shown. All of the containers have the same volume of an identical liquid.



Rank the buoyant force exerted by the liquid on the blocks.

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

Explain your reasoning.

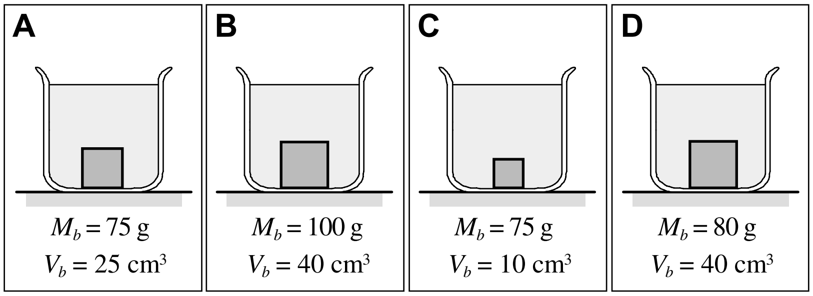
Answer: D > C > A = B.

Since the blocks are floating the buoyant forces have to be equal to the weights of the blocks, which are proportional to the masses of the blocks.

Note: The figures do not accurately show the percentages immersed of the blocks.

C2-RT07: Blocks at the Bottom of Liquids—Buoyant Force

In each case, a block is at rest at the bottom of a beaker filled with liquid. The blocks are made of different materials and vary in mass and volume, as shown. The liquid is the same in each beaker, and the liquid levels after the blocks are added are the same for all four beakers.



Rank the buoyant force exerted by the liquid on the blocks.

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

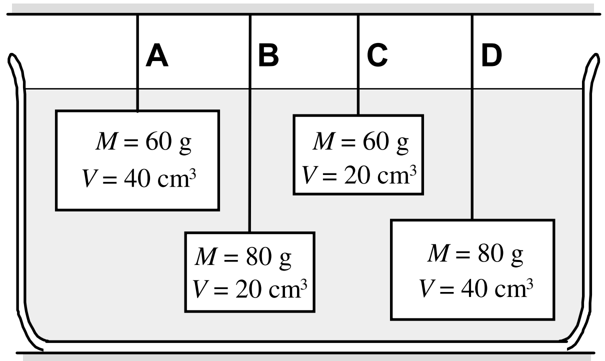
Explain your reasoning.

Answer: B = D > A > C.

Since these blocks are all fully immersed in the liquid the buoyant forces are equal to the weights of the fluid displaced. How much fluid is displaced in each case is determined by the volume of the block.

C2-RT08: Four Metal Cubes Suspended in Liquids—Tension

Four blocks are suspended from strings in water. Cubes A and C are at the same depth, as are B and D.



Rank the tensions in the strings.

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

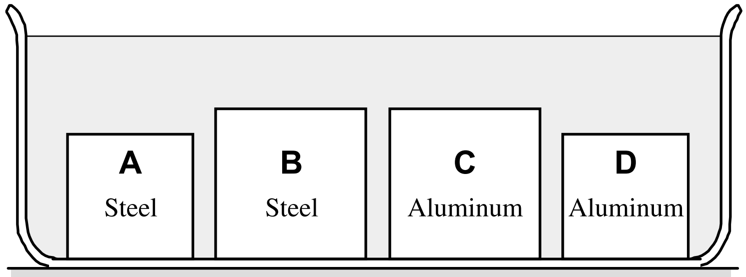
Explain your reasoning.

Answer: B > C = D > A.

The net force on each block is zero, since they are all at rest. The tension plus the buoyant force must have the same magnitude as the weight. B has the largest weight and smallest buoyant force, which is proportional to the volume of the block. A and D have the same buoyant force but different weights, so D will have a larger tension than A. C, which has the same weight as A, but a smaller buoyant force, will have the same tension as D.

C2-RT09: FOUR SUBMERGED CUBES—BUOYANT FORCE

Shown are small cubes that are 10 cm on a side and larger ones that are 12 cm on a side that are submerged in water. Cubes A and B are made of steel ($\rho = 7$ g/cm^3) and cubes C and D are made of aluminum ($\rho = 2.7$ g/cm^3).



Rank the buoyant force exerted on the cubes by the water.

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

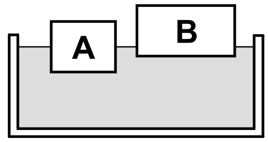
Explain your reasoning.

Answer: B = C > A = D.

The buoyant forces are equal to the weight of water displaced, and are therefore proportional to the volumes of the cubes.

C2-CT10: TWO FLOATING BLOCKS—BUOYANT FORCE

Two blocks with the same weight but different dimensions are floating in water at different levels. Block A is as tall as block B but is smaller in both other dimensions.



Is the buoyant force exerted by the water on block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the buoyant force on block B? _____

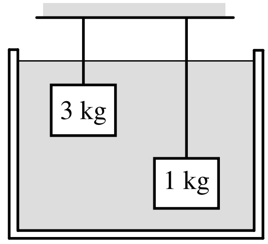
Explain your reasoning.

Answer: (c) The buoyant forces are equal.

The net force on each block is zero since each block is at rest. Since the blocks have the same weight, they must also have the same buoyant force.

C2-CT11: TWO SUBMERGED CUBES—BUOYANT FORCE, TENSION, AND PRESSURE

Two equal-sized cubes that have different masses are held by strings so that they are submerged in water at different depths.



(a) Is the buoyant force exerted by the water on the 3 kg cube (i) *greater than*, (ii) *less than*, or (iii) *equal to* the buoyant force on the 1 kg cube? _____
Explain your reasoning.

Answer: c. Equal to.

The buoyant force is proportional to the volume of the cube.

(b) Is the tension in the sting holding the 3 kg cube (i) *greater than*, (ii) *less than*, or (iii) *equal to* the tension in the string holding the 1 kg cube? _____
Explain your reasoning.

Answer: a. Greater than.

Since the 3 kg cube has the larger weight when we subtract the buoyant force, which will have the same magnitude for both cubes, we end up with a larger tension.

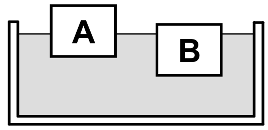
(c) Is the pressure exerted on the bottom surface of the 3 kg cube by the water (i) *greater than*, (ii) *less than*, or (iii) *equal to* the pressure on the bottom surface of the 1 kg cube? _____
Explain your reasoning.

Answer: b. Less than.

The pressure will be determined by the depth in the liquid.

C2-CT12: FLOATING CUBES—BUOYANT FORCE AND PRESSURE

Two equal-sized cubes are floating in water at different levels.



(a) Is the buoyant force exerted by the water on block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the buoyant force on block B? _____
Explain your reasoning.

Answer: (b) Less than.

The buoyant force is proportional to the volume of the cube that is immersed in the water.

(b) Is the weight of block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the weight of block B? _____
Explain your reasoning.

Answer: (b) Less than.

The buoyant force has to balance the weight for both of these cubes, so A, which is experiencing a smaller buoyant force, must have a smaller weight.

(c) Is the pressure exerted on the bottom surface of block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the pressure on the bottom surface of block B? _____
Explain your reasoning.

Answer: (b) Less than.

The bottom surface of A is at a shallower depth in the water.

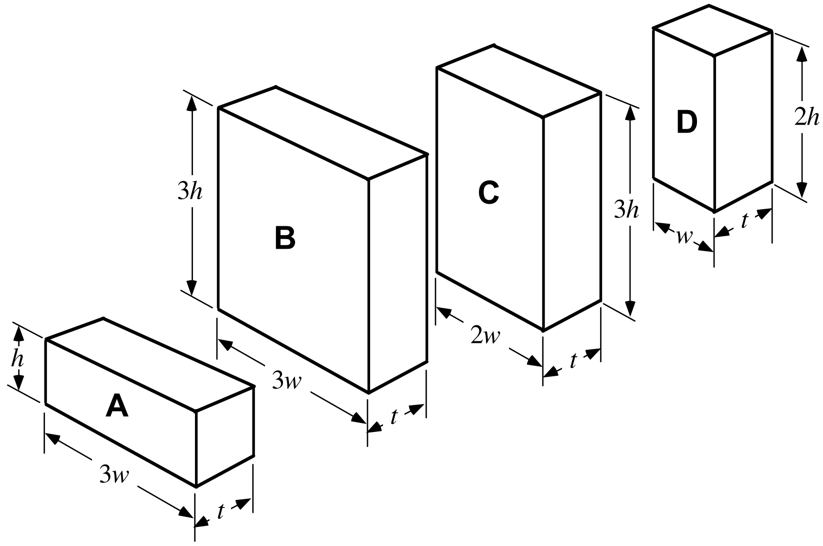
(d) Is the density of block A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the density of block B? _____
Explain your reasoning.

Answer: (b) Less than.

They have the same volume, but the mass of A is smaller.

C2-RT13: FOUR RECTANGULAR BLOCKS—PRESSURE

Four rectangular blocks are made of the same material, with dimensions as shown.



(a) Rank the mass of each block.

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

Explain your reasoning.

Answer: B > C > A > D.

Since the blocks are all made of the same material, the masses are proportional to the volumes of the blocks.

(b) The blocks are placed as shown onto a table. Rank the pressure exerted by the blocks on the table.

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

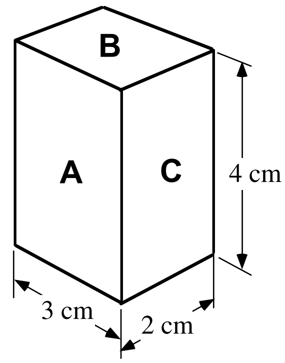
Explain your reasoning.

Answer: B = C > D > A.

The pressure is force/area and the force is proportional to the volume—which is proportional to the weight, i.e., the force acting on the table. The area is the area of the face sitting on the table. Thus the ranking is based on the height since area cancels out.

C2-RT14: Rectangular Block—Pressure

A rectangular block is at rest on a table. Three faces of the block are labeled A, B, and C. Face A has dimensions 3 cm x 4 cm; face B has dimensions 2 cm x 3 cm; and face C has dimensions 2 cm x 4 cm.



Rank the pressure exerted by the block on the table when it is resting on each labeled face.

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

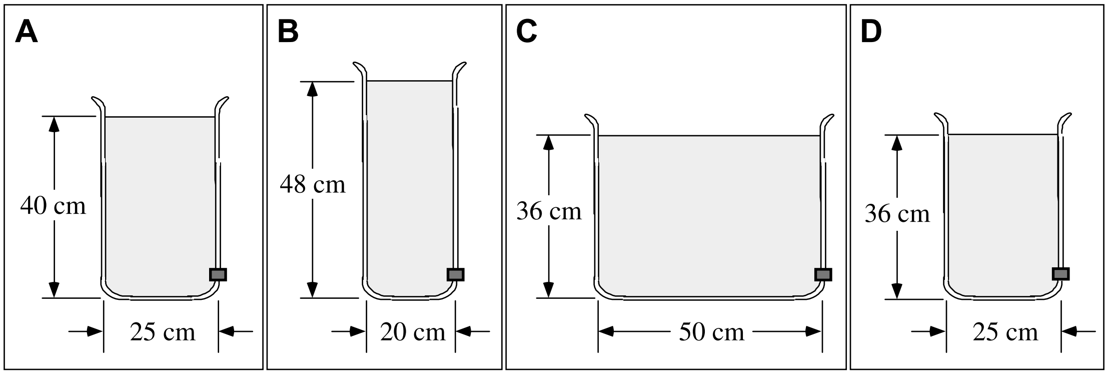
Explain your reasoning.

Answer: B > C > A.

Since pressure is defined as the force—which will be the weight of the block in all three cases, divided by the area over which it acts, the block will exert a larger pressure when supported on smaller faces.

C2-RT15: BEAKERS OF WATER—PRESSURE ON THE CORK

In each case a beaker is filled with water to the height shown. The diameters of the beakers are also shown. The cylinders have identical holes in their side at the same height above the base. There are corks in all of the holes.



Rank the pressure exerted on the cork by the water.

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

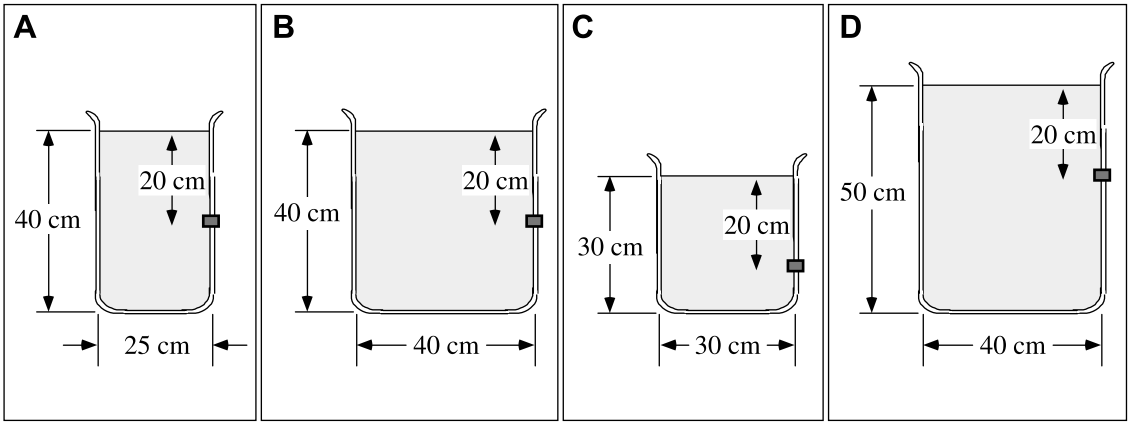
Explain your reasoning.

Answer: B > A > C = D.

The pressure in a standing liquid depends on the density of the liquid and the depth of the liquid. Since all the liquids are the same the pressure depends on depth only.

C2-RT15: Beakers of Water—Cork Pressure

Shown are various beakers filled with water. The diameters of the beakers and the heights of the water to which they are filled are also shown. The beakers have identical holes filled with corks in the side at the specified depths.



Rank the pressure exerted on the cork by the water.

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

Explain your reasoning.

Answer: all the same.

Pressure in a standing fluid is determined by the density of the fluid and the depth. Since all of the corks are at the same depth in the same liquid, the pressure is the same for all.

C2-WWT16: WATER IN PIPE—SPEED

Water is flowing through a pipe, filling it completely. The pipe narrows to half its diameter from one section to the next. A physics student makes the following comparison of the speed of the water in the two sections:

"Since the diameter of the pipe has been cut in half, but the same amount of water still has to get through the pipe, in the smaller section the speed of the water has to double."

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

Answer: This is wrong.

The same volume of water has to pass each point each second in both segments of the pipe or conservation of matter will be violated. The volume passing a point per second will be given by the product of the area of the pipe times the speed. Cutting the diameter in half reduces the area by one-fourth, so the speed has to quadruple.

C3 HEAT AND TEMPERATURE

C3-SCT01: FAHRENHEIT TEMPERATURE CHANGE—CENTIGRADE TEMPERATURE CHANGE

Several students are discussing temperature conversions between Fahrenheit and Centigrade scales. They are considering a temperature change of 45 degrees Fahrenheit (°F).

Ariel: *"Since in going from Fahrenheit to Centigrade we have to use 5/9 (45°F + 32°F), a temperature change of 45 °F is a change of 43 °C."*

Brent: *"I think this is a temperature change of 25 °C because all we have to do is take 5/9 (45°F)."*

Coen: *"No, you are both making this hard. A temperature change of 45 °F is 45°C since no conversion is needed for changes in temperature, just for specific temperatures."*

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

Ariel _____ Brent _____ Coen _____ None of them_____

Explain your reasoning.

Answer: Brent is correct.

We do not have to worry about the offset for the freezing point of water—0 °C = 32 °F—all we are concerned with is the difference between the initial and final temperatures.

C3-WWT02: CENTIGRADE TEMPERATURE CHANGE— KELVIN CHANGE

A student discussing a change in temperature states:

"A temperature change of 200 °C is also a 200 degree change in the Kelvin system."

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 correct.

The size of the degree is the same for both of these scales; it is only the location of the zero which varies.

C3-WWT03: Mixing Liquids—Final Temperature

A student mixes 100 g of liquid A at a temperature of 80 °C with 100 g of liquid B at a temperature of 20 °C. After the mixture comes to thermal equilibrium, it has a temperature of 40 °C. The student contends:

"If I mix 100 g of liquid A at a temperature of 60 °C with 100 g of liquid B at a temperature of 30 °C, I will also end up with a 200 g mixture at a temperature of 40 °C."

What, if anything, is wrong with the student's contention? If something is wrong, identify it and explain how to correct it. If nothing is wrong, explain the physics behind the student's answer.

Answer: This contention is correct.

When the liquids were initially mixed the final temperature was one-third of the initial temperature difference higher than B's initial temperature. This means it takes twice as much energy to change the temperature of a gram of B as it does for A. So in the second mixture if we take one-third of the initial temperature difference and add that to the initial temperature of B we will get the final temperature of the mixture.

C3-WWT04: BOILING WATER—TEMPERATURE

Two pans of water are being heated on two burners on a stove. In pan A the water is boiling vigorously, but in pan B the water is boiling at a much slower rate. A student contends that:

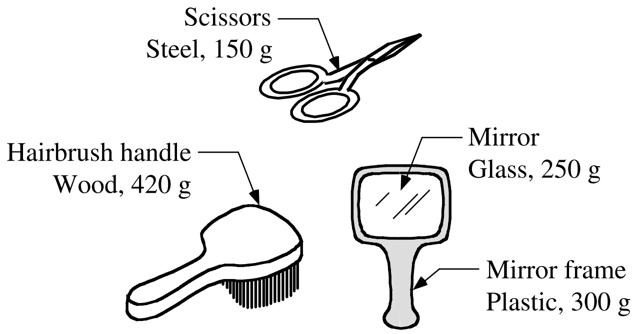
"The temperature of the water in the pan that is boiling vigorously is a little higher than the other pan because it has definitely reached the boiling point."

What, if anything, is wrong with this student's contention? If something is wrong, identify it and explain how to correct it. If nothing is wrong, explain why the statement is valid.

Answer: The temperature will be the same in both pans since the water in both is boiling, which means the temperature has reached 100 °C.

C3-SCT05: OBJECTS IN A ROOM—TEMPERATURE

The objects shown have been sitting untouched on a bedside table overnight. The room they are in has been at a constant temperature of 25 °C.



Four students are discussing the temperatures of these objects.

Abigail: *"All of the objects have been sitting there all night. They will be at the same temperature as the room."*

Beto: *"That can't be—if you touch them you can feel the differences. I think the scissors will have the lowest temperature, then the glass of the mirror, then the plastic mirror frame. The wood will be warmest."*

Carlos: *"I agree with Beto that the temperatures will be different, but I think you have to pay attention to the masses as well. The actual temperature depends on the material and the mass, with the more massive objects keeping cooler. It's hard to say whether the scissors will have a lower temperature than the mirror glass, and it's also hard to say whether the plastic will be warmer than the wood, but the mirror and metal will definitely be cooler than the wood and plastic."*

Dave: *"I think the mirror and the mirror frame are going to transfer heat to each other until they are the same temperature, because they are in contact. They'll reach some temperature that is between the cold scissors and the warm brush handle."*

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

Abigail _____ Beto _____ Carlos _____ Dave _____ None of them_____

Explain your reasoning.

Answer: Abigail is correct.

Since the materials have all been at the same temperature for a long time, they will all have come to thermal equilibrium at the room temperature. The glass mirror and steel scissors will feel cooler because they conduct heat better than the others.

C3-CT06: Combining Water, Steam, or Ice—Final Mass and Final Temperature

In three experiments described below, combinations of water (liquid), steam (gas), and ice (solid) are mixed together in an insulated container, and are allowed to reach thermal equilibrium.

First, 40 g of water at 100 °C and 60 g of water at 0 °C are mixed together.

(a) When the mixture reaches thermal equilibrium, will the mass of water be (i) *greater than*, (ii) *less than*, or (iii) *the same as* the sum (100 g) of the two initial masses of water? _____

Explain your reasoning.

Answer: (iii) the same.
The final mass will be the same as the sum since we are mixing two samples of liquid water that end up with a temperature between 0 and 100 °C.

(b) When the mixture reaches thermal equilibrium, will the final temperature of the system be (i) *greater than*, (ii) *less than*, or (iii) *equal to* 50 °C? _____

Explain your reasoning.

Answer: (ii) **less than.**
We have a larger mass at the lower temperature so the final temperature will be below 50 °C.

Next, 50 g of steam at 100 °C and 50 g of water at 80 °C are mixed together in a different insulated container.

(c) When the combination reaches thermal equilibrium, will the mass of water (liquid) be (i) *greater than*, (ii) *less than*, or (iii) *the same as* the sum (100 g) of the two initial masses? _____

Explain your reasoning.

Answer: (ii) **less than.**
The final mass of liquid will be less than the sum of the two masses. In this case not all of the steam will be converted to liquid, so the equilibrium temperature will be 100 °C and will be a mixture of liquid water with a fraction of the steam.

(d) When the mixture reaches thermal equilibrium, will the temperature of the system be (i) *greater than*, (ii) *less than*, or (iii) *equal to* 90 °C? _____

Explain your reasoning.

Answer: (i) **greater than.**
As explained above the final temperature of the mixture will be 100 °C.

Finally, 40 g of liquid water at 20 °C and 60 g of ice at 0 °C are mixed together in another insulated container.

(e) When the combination reaches thermal equilibrium, will the mass of water (liquid) be (i) *greater than*, (ii) *less than*, or (iii) *equal to* 100 g? _____

Explain your reasoning.

Answer: (ii) **less than.**
Since the mass of ice is larger than the mass of water, not all of the ice will melt.

(f) When the mixture reaches thermal equilibrium, will the temperature of the system be (i) *greater than*, (ii) *less than*, or (iii) *equal to* 10 °C? _____

Explain your reasoning.

Answer: (ii) **less than.**
The final mixture will be both liquid water and ice, so its temperature will be 0 °C.

C3-CT07: WATER AND ICE—TEMPERATURE

One student at a restaurant asks for water with lots of ice, while another asks for only a little ice. The waiter uses bottled water from the same bottle and ice from the same ice bucket to fill the order. There is still ice left in both glasses when the ice water comes to thermal equilibrium.

Will the temperature of the water in the glass with only a little ice be (i) *greater than*, (ii) *less than*, or (iii) *the same as* the temperature of the water in the glass with a lot of ice? _____

Explain your reasoning.

Answer: (iii), the temperature will be the same in both glasses.

Both glasses contain mixtures of ice and water in equilibrium at a temperature of 0 °C.

C3-CT08: PREPARING COFFEE—TIME TO HEAT

A teacher prepares a cup of instant coffee by heating 200 g of water that was initially at 20 °C with an electric immersion heater placed directly in the cup. It takes 207 seconds to warm the water to 90 °C.

(a) Another teacher with an identical cup uses the same heater to warm up 150 g of water, initially at 20 °C. Is the time taken to heat this second cup of water to 90 °C (i) *greater than*, (ii) *less than*, or (iii) *equal to* 207 seconds? _____

Explain your reasoning.

Answer: (ii) **less than.**

It takes less time to heat the second cup because there is less water to heat up and the temperature difference is the same.

(b) A third teacher with an identical cup uses the same heater to warm up 200 g of warmer water, initially at 30 °C. Is the time taken to heat this third cup of water to 90°C (i) *greater than*, (ii) *less than*, or (iii) *equal to* 207 seconds? _____

Explain your reasoning.

Answer: ii) **less than.**

It takes less time because the water is warmer to start with and requires less energy to heat up to the 90 °C final temperature.

(c) A fourth teacher with an identical cup uses the same heater to warm up 200 g of colder water, initially at 10 °C. Is the time taken to heat this fourth cup of water to a very warm 80 °C (i) *greater than*, (ii) *less than*, or (iii) *equal to* 207 seconds that it took for the first teacher to heat the water? _____

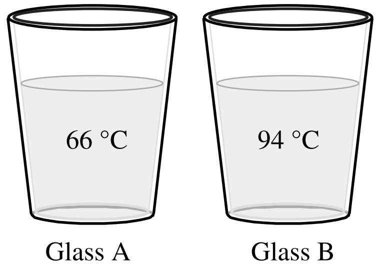
Explain your reasoning.

Answer: (iii) **equal to.**

In this case the same mass of water undergoes the same temperature change.

C3-TT09: TWO GLASSES OF WATER—AMOUNT OF HEAT

Two glasses each contain 500 mL samples of water. The water in glass A has a temperature of 66 °C, and the water in glass B has a temperature of 94 °C.



A student makes the following contention:

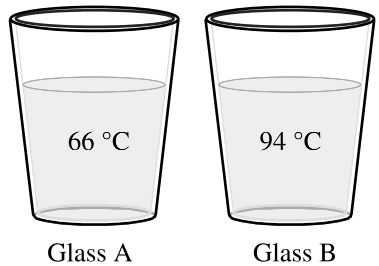
"Since both glasses have the same amount of water, but Glass B has a higher temperature, Glass B contains more heat."

There is a problem with this student's contention. Identify the problem and explain how to correct it.

Answer: The problem is that we cannot say that an object contains a certain amount of heat. What we call heat is the energy that is exchanged by a system with its surroundings during a process where the temperature of the system and it surroundings initially vary. We can say that glass B has more internal, or thermal, energy, but how much energy was added to each sample via heating depends on how they were heated.

C3-CT10: Combining Two Glasses of Water—Final Temperature

Two glasses each contain 500 mL samples of water. The water in glass A has a temperature of 66 °C, and the water in glass B has a temperature of 94 °C. The two glasses are mixed together in a larger glass.



Is the final temperature of the mixture (i) *greater than*, (ii) *less than*, or (iii) *the same as* the average temperature of 80 °C of the two glasses? _____

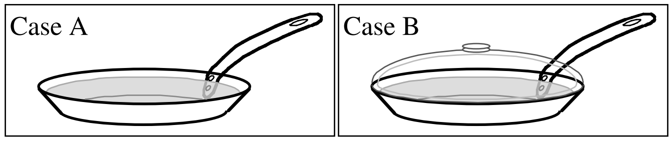
Explain your reasoning.

Answer: (iii) same as.

Since we are combining equal masses of the same liquid the final temperature will be the average.

C3-TT11: Two Pans of Water—Amount of Heat Added

Two pans each contain the same amount of water. The water in each pan started out at 20 °C, and both pans were heated until the water reached a temperature of 94 °C. The pan in Case A was left open while it was heating, and the pan in Case B had a tight glass lid over it while the water was heating.



A student makes the following contention:

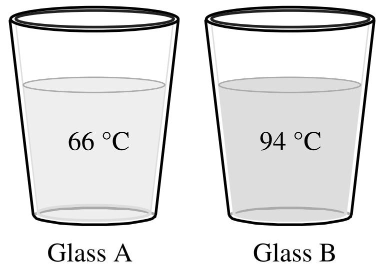
"Since both pans have the same amount of water and both were heated from the same initial temperature to the same final temperature, the same amount of heat had to be added to both."

There is a problem with the student's contention. Identify the problem and explain how to correct it.

Answer: The student's contention is wrong because the two samples underwent different processes to reach their final temperature. In case A, the pressure was constant, while in case B the pressure increased as the water was heating. In addition, in case A the more energetic molecules from the water that escaped as vapor were subsequently (mostly) removed, whereas in case B most of these molecules condensed on the glass and returned to the liquid. Because the processes were different, the amount of energy exchanged between the water and its surroundings as heat was different. The energy transferred between a system and its surroundings as heat depends on the particulars of the process and not just on the starting and ending states.

C3-CT12: COMBINING TWO GLASSES OF DIFFERENT LIQUIDS—FINAL TEMPERATURE

Two glasses each contain 500 mL samples of liquid. The liquid in Glass A has a temperature of 66 °C, and the liquid in Glass B has a temperature of 94 °C. The liquid in Glass A has a larger specific heat than the liquid in Glass B. The two glasses are mixed together in a larger glass.



Is the final temperature of the mixture (i) *greater than*, (ii) *less than*, or (iii) *the same as* the average temperature of 80 °C of the two glasses? _____

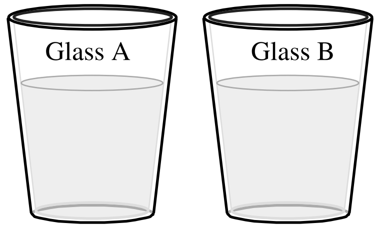
Explain your reasoning.

Answer: (ii) less than.

Since the liquid in glass has a larger specific heat that means it needs more energy to increase the temperature of each unit mass by one degree. The masses in the two glasses are the same, so the final temperature will end up closer to the initial temperature of A.

C3-CT13: THERMAL ENERGY IN TWO GLASSES OF WATER—TEMPERATURE*

(a) Two identical glasses contain equal samples of water. The water in Glass A has twice the thermal (internal) energy as the water in Glass B.

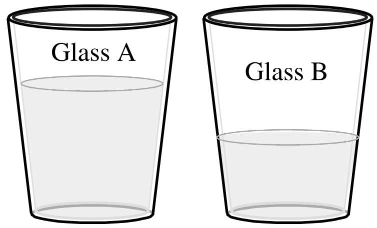


Is the temperature of Glass A (i) *greater than,* (ii) *less than*, or (iii) *the same as* the temperature of Glass B? Explain your reasoning.

Answer: (i) greater than.

Thermal(internal) energy includes the kinetic energy of the sample, since these two have the same mass the average kinetic energy of A has to be larger. Temperature is the measure of the average kinetic energy.

(b) Two identical glasses contain different samples of water. Glass A contains 500 mL of water, and Glass B contains 250 mL of water. The water in Glass A has twice the thermal (internal) energy as the water in Glass B.

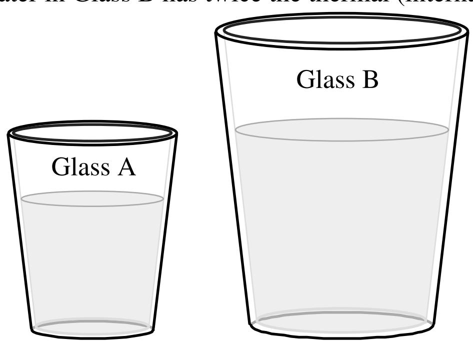


Is the temperature of Glass A (i) greater than, (ii) less than, or (iii) the same as the temperature of Glass B? Explain your reasoning.

Answer: (iii) same as.

Glass A has twice the mass and twice the internal energy, so the samples have to have the same temperature.

(c) Two different glasses contain different samples of water. Glass A contains 500 grams of water, and Glass B contains 750 grams of water. The water in Glass B has twice the thermal (internal) energy as the water in Glass A.



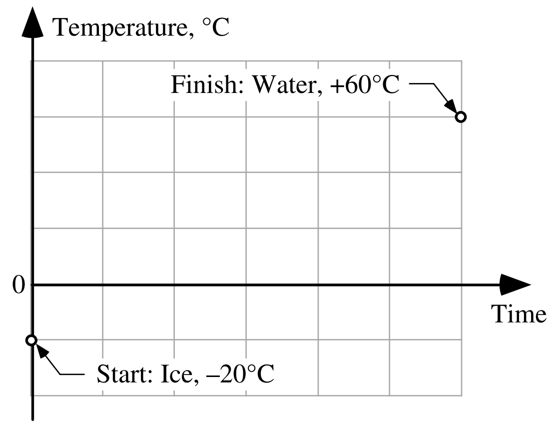
Is the temperature of Glass A (i) greater than, (ii) less than, or (iii) the same as the temperature of Glass B? Explain your reasoning.

Answer: (i) greater than.

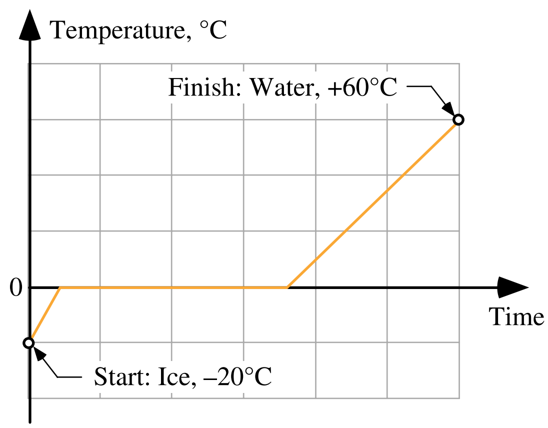
C3-CRT14: MELTING AN ICE CUBE—TEMPERATURE-TIME GRAPH

An ice cube at a temperature of −20 °C is put in a plastic bowl and placed in a microwave oven, and the oven is turned on. When the oven is turned off, the bowl contains water at a temperature of +60 °C.

Assuming the microwave transferred energy to the ice at a constant rate throughout, draw a graph (below) of the temperature of the H_2O as a function of time. The endpoints of the graph are given.



Explain why your graph looks the way it does.



Answer: The ice will initially warm up until it reaches its melting point of 0 °C, then its temperature will be constant while it melts. After all the ice is melted at 0 °C, the temperature will increase linearly to its final value. The slope is less in the liquid phase than in the solid (ice) phase, because water has a larger specific heat as a liquid than as a solid. That is, the amount of energy that must be transferred to a gram of ice to heat it 1 °C is less than the amount of energy that must be transferred to a gram of water to heat it 1 °C, so for a given amount of heat transferred, there is a larger temperature change for ice than water.

C3-CT15: HEATING ICE—FINAL TEMPERATURE

Suppose we heat sample A, which is 150 g of ice at –10 °C, and sample B, which is 150 g of ice at 0 °C, in the same microwave until both samples are water at 30 °C.

Will the time taken to heat sample A be (i) *longer than*, (ii) *shorter than*, or (iii) *equal to* the time to heat sample B? _____

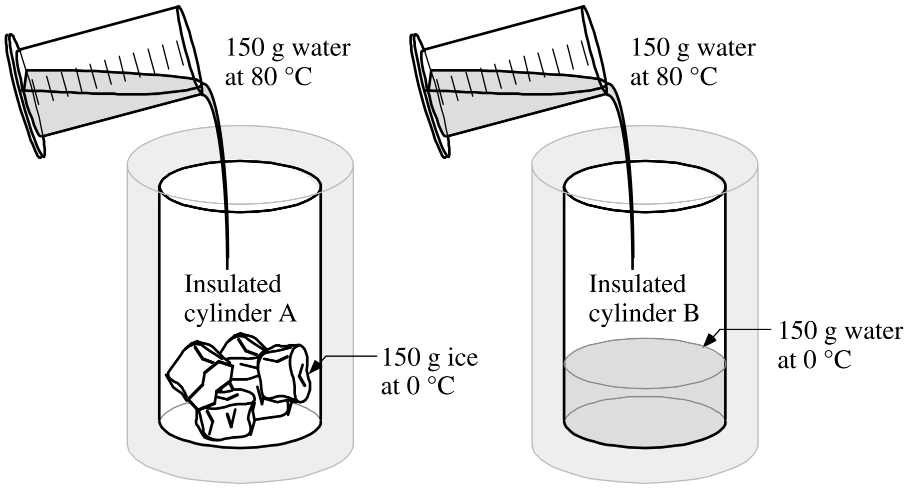
Explain your reasoning.

Answer: (i) longer

Energy will be needed to heat the ice of sample A from –10 °C to 0 °C before it can start to melt.

C3-CT16: MIXING WATER AND/OR ICE—TEMPERATURE

Insulated cylinder A initially contains 150 g of ice at 0 °C, and insulated cylinder B initially contains 150 g of water at 0 °C. To each cylinder, 150 g of water at 80 °C is added, and the contents of the cylinders are stirred and then left to reach thermal equilibrium.



Will the final temperature of the mixture in cylinder A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the final temperature of the mixture in cylinder B? _____

Explain your reasoning.

Answer: (ii) less than.

Less than because in cylinder A most of the energy that the water at 80 °C transfers to the ice will go into melting the ice.

C3-CT17: USING A STEEL TAPE AT DIFFERENT TEMPERATURES—ACTUAL LENGTH

A surveyor's 100 m steel tape is calibrated to be precise to 0.1 mm at a temperature of 15 °C. A distance between two points is measured as 63.7300 m with this steel tape on a 40 °C day. The linear temperature coefficient of expansion for steel is α_{Steel} = 11 x 10-6/°C.

Is the actual (or correct) distance (i) *shorter than*, (ii) *longer than*, or (iii) *the same as* the measured distance of 63.7300 m? _____

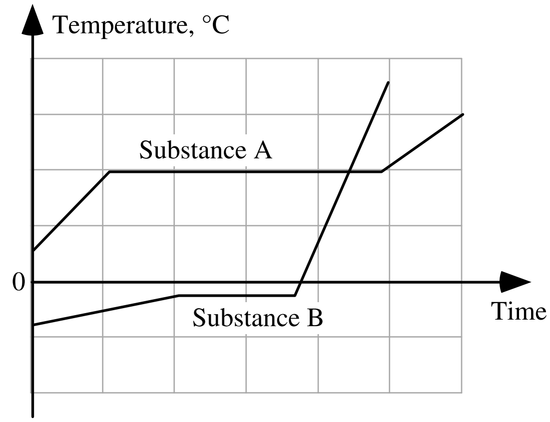
Explain your reasoning.

Answer: (i) the actual distance is shorter.

The length of the tape will be greater at 40 degrees compared to its length at 15 degrees at which the tape was calibrated.

C3-CT18: TEMPERATURE-TIME GRAPH—PROPERTIES OF SAMPLES

Samples of two pure substances are heated at a constant rate, and their temperature as a function of time is recorded. Both substances started as solids and melted. The mass of the two samples is the same.



Is the melting point of substance A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the melting point of substance B? _____

Explain your reasoning.

Answer: (i) greater than.

We can read this off the graph as the temperature on the vertical axis where the horizontal plateau occurs.

Is the specific heat of substance A in its solid state (i) *greater than*, (ii) *less than*, or (iii) *equal to* the specific heat of substance B in its solid state? _____

Explain your reasoning.

Answer: (ii) less than.

A has a higher slope in the solid phase meaning it takes less energy to increase the temperature for A. That is, the amount of energy that must be transferred to a gram of substance A to heat it 1 °C is less than the amount of energy that must be transferred to a gram of substance B to heat it 1 °C, so for a given amount of heat transferred, there is a larger temperature

Is the latent heat of fusion of substance A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the latent heat of fusion of substance B? _____

Explain your reasoning.

Answer: (i) greater than.

The latent heat of fusion is the amount of energy that must be transferred to the substance per unit mass to melt it. The time to melt is the length of the horizontal plateau in temperature where added energy is not changing the temperature, but is instead changing the phase of the material from solid to liquid. Since substance A took more time to melt, and both samples have the same mass, the amount of energy required to melt substance A was greater than the amount of energy

C3-CT19: HEATED BEAKER FILLED WITH GLYCERIN—OVERFLOW

A glass beaker is partially filled with 500 cm^3 of glycerin at 15 °C. The beaker and the glycerin are then heated to 40 °C. The thermal linear coefficient of expansion for the glass is $\alpha_{glass} = 3 \times 10^{-6}/°C$. The thermal volume coefficient of expansion for glycerin is $\beta_{Glycerin} = 5.1 \times 10^{-4}/°C$.

As the beaker and contents are heated, will the glycerin level (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

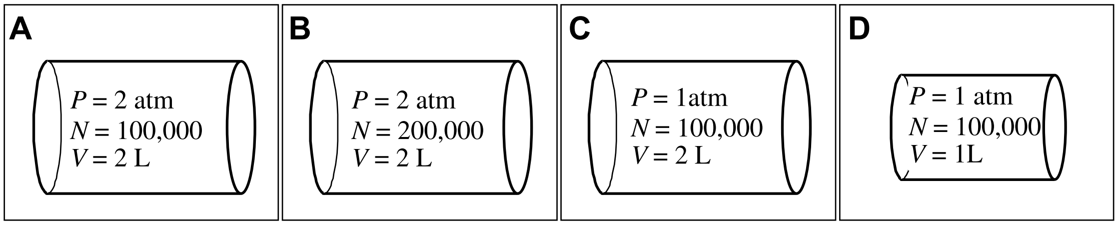
Explain your reasoning.

Answer: (i) increase.

The glycerin level will increase since its volume expansion is larger than the volume expansion of the glass. The volume coefficient of expansion for the glass is 3 times the linear coefficient of expansion.

C3-RT20: IDEAL GAS SAMPLES—TEMPERATURE I

Four sealed containers hold different amounts of an ideal gas at different temperatures and pressures. The pressure *P* of the gas is given in each case, as is the number of molecules *N* and the volume *V*.



Rank the temperatures of these ideal gas samples.

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

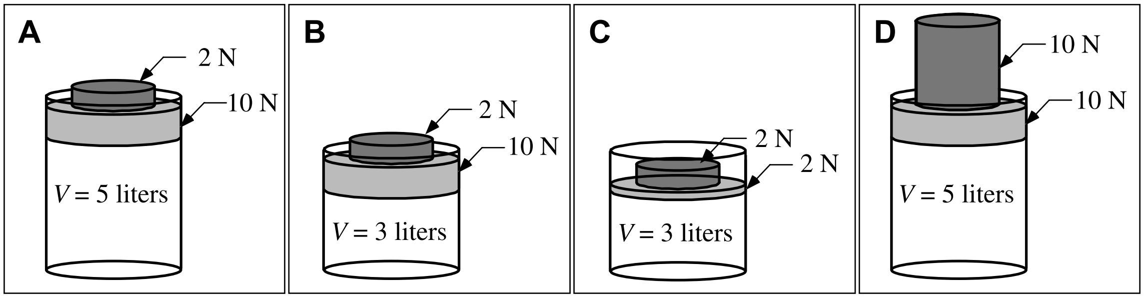
Explain your reasoning.

Answer: A > B = C > D.

By the Ideal Gas Law the temperatures are proportional to the product of the pressure and volume divided by the number of molecules. Here the pressure times the volume is 4 liter-atmospheres in cases A and B, 2 liter-atmospheres in case C, and 1 liter-atmospheres in case D. Since A, C, and D all have the same number of particles, A > C > D. Since temperature is proportional to PV/N, the temperatures in cases B and C will be the same.

C3-RT21: IDEAL GAS IN CYLINDERS WITH MOVEABLE PISTONS I—PRESSURE

Cylinders with equal cross-sectional areas contain different volumes of an ideal gas sealed in by pistons. There is a weight sitting on top of each piston. The gas is the same in all four cases and is at the same temperature. The pistons are free to move without friction.



Rank the pressure of the gas in each cylinder.

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

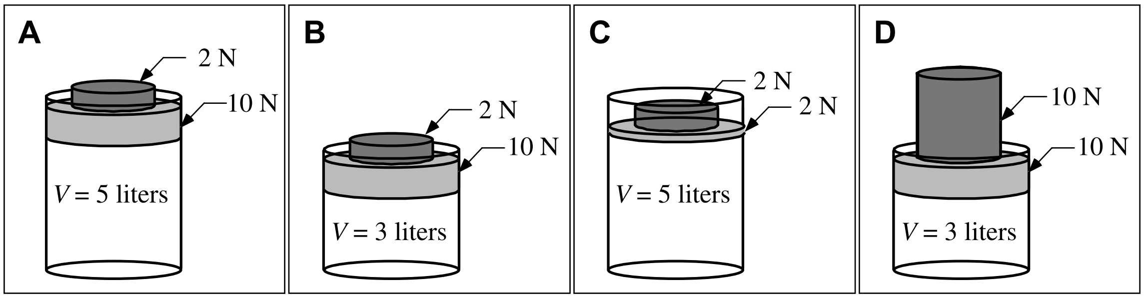
Explain your reasoning.

Answer: D > A = B > C.

Since pressure is defined as the force divided by area and all the pistons have the same area, the pressure is determined by the total weight of the piston and added mass. (It helps to think about a free-body diagram of a system consisting of the piston plus the weight: The combined weight acts down and the force from the gas acts up.)

C3-RT22: Gas in Cylinders with Moveable Pistons—Mass

Cylinders with equal cross-sectional areas contain different volumes of an ideal gas sealed in by pistons. There is a weight sitting on top of each piston. The gas is the same in all four cases and is at the same temperature. The pistons are free to move without friction.



Rank the mass of the gas in the cylinders.

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

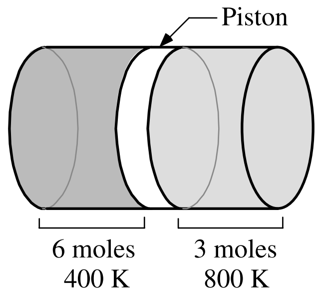
Explain your reasoning.

Answer: A = D > B > C.

From the ideal gas law, the mass of the gas is proportional to the product of the pressure and volume since the temperature is the same for all samples. The mass of the gass will be proportional to the number of moles of gas since the gases are all the same and each mole of gas has the same mass.

C3-CT23: Ideal Gases in a Cylinder—Pressure

A cylinder contains two samples of different ideal gases. A piston separating the two gases is free to move without friction. Each gas occupies half of the cylinder, but there are twice as many molecules on the left side of the piston as on the right, and the absolute temperature is twice as large for the gas on the right side as for the gas on the left.



Is the pressure in the gas on the left side (i) *greater than*, (ii) *less than*, or (iii) *equal to* the pressure in the gas on the right side? _____

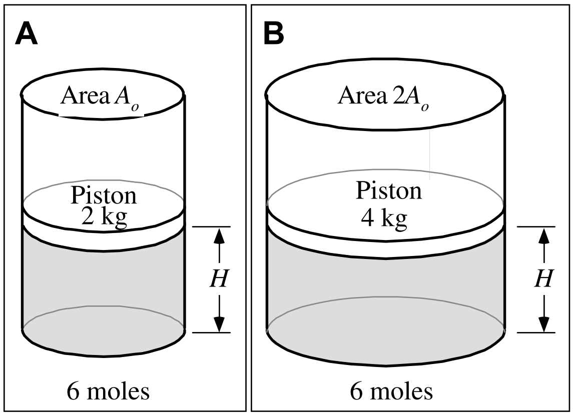
Explain your reasoning.

Answer: (iii) equal.

The volumes of the two gases are the same and the products of the number of moles and the absolute temperatures of the gases are also the same. Consequently, according to the ideal gas law the pressures have to be equal. (Another way to reason about this is that if the pressures were not equal there would be a net force on the piston and it would not be at rest.)

C3-CT24: IDEAL GASES IN CYLINDERS—TEMPERATURE

Two cylinders are filled to the same height H with ideal gases. The gases are different, and the cross-sectional areas of the cylinders are different. Both cylinders have pistons that are free to move without friction.



Is the temperature of the gas in cylinder A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the temperature of the gas in cylinder B? _____

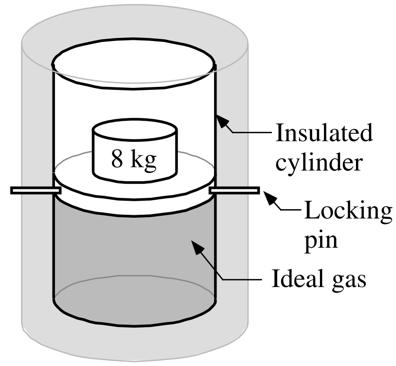
Explain your reasoning.

Answer: (ii) less than.

There is no net force on the piston, since it is at rest, so the weight of the piston must be equal in magnitude to the force exerted on the piston by the gas. The force exerted by the gas is therefore twice as great in case B. This force is the product of the pressure and the area of the cylinder, and since the area in case B is also twice as great as in case A, the pressures of the gases are the same. The volume of the gas in case B is twice the volume of the gas in case A, and the pressures are the same, as are the number of moles. From the ideal gas law, then, the absolute temperature in case B will be double the absolute temperature in case A.

C3-WWT25: IDEAL GAS IN AN INSULATED CYLINDER I—TEMPERATURE CHANGE

An insulated cylinder contains an ideal gas. The cylinder has a piston that is initially locked in place with pins. When the pins are moved outward, the piston can move freely without friction. On top of the piston is an 8 kg metal disc. A student who is asked what will happen to the temperature of the gas after the piston is unlocked makes the following contention:



"The piston will move, but we don't know which way. Whether it moves up or down, though, since the cylinder is insulated, the temperature of the gas cannot change during the process."

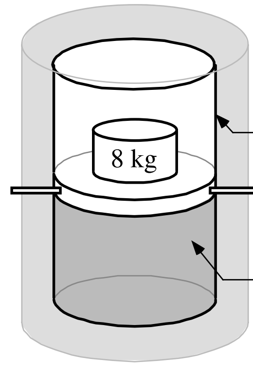
What, if anything, is wrong with the student's contention? If something is wrong, identify it and explain how to correct it. If nothing is wrong, explain the physics behind the student's answer.

Answer: The student is correct that we do not know which way the piston will move (if it moves at all), but is not correct about the temperature.

If the piston moves upward the gas will have done work on the piston and metal cylinder, and if it moves downward there will be work done on the gas by the piston and cylinder. In either case, the internal energy of the gas changes, which corresponds to a change in the temperature of the gas. The insulated cylinder prevents energy exchange between the gas and the environment via heating, but this alone does not prevent a change in temperature.

C3-WWT26: IDEAL GAS IN AN INSULATED CYLINDER II—TEMPERATURE CHANGE

An insulated cylinder contains an ideal gas. The cylinder has a piston that is initially locked in place with pins. On top of the piston is an 8 kg metal disc. When the pins are moved outward, the piston moves downward without friction, coming to rest 2 cm below its initial position. A student who observes this piston motion makes the following contention:



"The piston will move down because the pressure of the gas was too low to support the combined weight of the piston and the metal cylinder. As the volume of the gas decreased, the pressure increased. These two effects compensate, and the temperature stays the same, which we also know since the cylinder is insulated, so the temperature of the gas cannot change during the process."

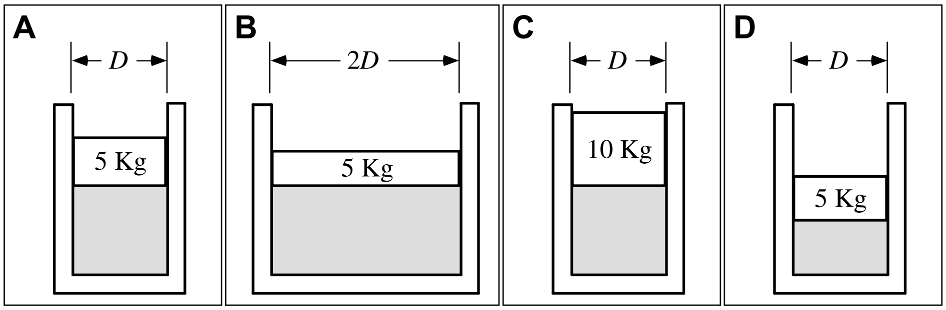
What, if anything, is wrong with the student's contention? If something is wrong, identify it and explain how to correct it. If nothing is wrong, explain the physics behind the student's answer.

Answer: The student is incorrect.

Since the gas is compressed when the piston is released, work is done on the gas by the piston, adding energy to the gas. No energy will be exchanged via heating since the container is insulated, so the internal energy of the gas will go up, and that means the temperature of the gas has to increase. As volume decreases, pressure increases, but the pressure will decrease by a greater factor than the factor by which the volume increases.

C3-RT27: Ideal Gas in Cylinders with Moveable Pistons II—Pressure

Each cylinder contains an ideal gas trapped by a piston that is free to move without friction. The pistons are at rest. All gases are at the same temperature. The diameter of the cylinder in Case B is twice the diameter of the cylinders in the other cases, and the mass of the piston in Case C is twice the mass in the other cases.



Rank the pressures of the gases.

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

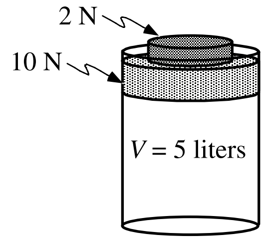
Explain your reasoning.

Answer: C > A = D > B.

There is no net force on the pistons, since the pistons are at rest. The force on the piston by the gas is therefore equal to the weight of the piston, and is the same in cases A, B, and D, and twice as large in case C. The pressure of the gas is the force divided by the area over which the force acts. The forces and areas are the same in cases A and D, so the pressures must be the same. The force is greater in case C with the same area as case A, so the pressure must be greater in case C than in case A. The area is greater in case B with the same force as in case A, so the pressure must be less in case B than in case A.

C3-LMCT28: HEAVY MOVEABLE PISTON IN CONTAINER WITH VOLUME—PRESSURE

An ideal gas is trapped in a container with a moveable, frictionless piston, and a metal disc is placed on top of the piston.



Identify from choices (i) – (iv) how the changes to this system described in (a) to (d) below affect the pressure of the gas in the cylinder.

This change will:

(i) **increase** the pressure of the system.
(ii) **decrease** the pressure of the system.
(iii) have **no effect** on the pressure of the system.
(iv) have an **indeterminate** effect on the pressure of the system.

All of these changes are made to the initial situation described above. In each case, the volume of gas in the cylinder is the same as above.

(a) The new system has a lighter piston but has the same metal disc placed on it. _____
Explain your reasoning.
Answer: (ii) decrease.

The pressure is proportional to the total weight supported by the gas, which has decreased.

(b) The new system has a heavier metal disc but has the same piston. _____
Explain your reasoning.
Answer: (i) increase.

The pressure is proportional to the total weight supported by the gas, which has increased.

(c) The new system has a lighter piston and a lighter metal disc. _____
Explain your reasoning.
Answer: (ii) decrease.

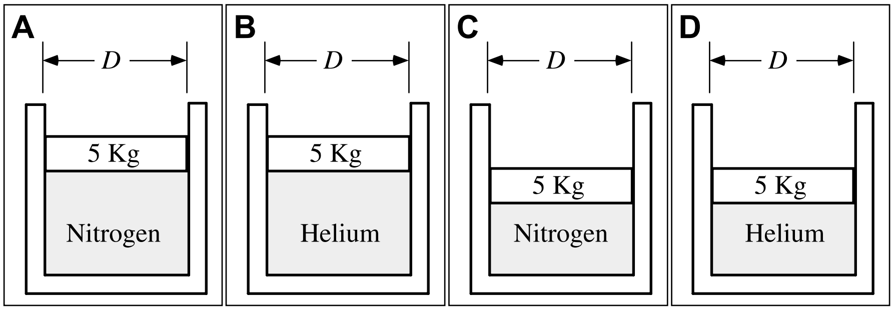
The pressure is proportional to the total weight supported by the gas, which has decreased.

(d) The new system has a smaller cross-sectional area cylinder and piston, but the weight of the piston is the same and the disc is the same. _____
Explain your reasoning.
Answer: (i) increase.

The pressure increases because the same force acts, but over a smaller area.

C3-RT29: IDEAL GASES IN CYLINDERS WITH A PISTON—PRESSURE

Each cylinder contains an ideal gas trapped by a piston that is free to move without friction. The pistons are at rest. All gases are at the same temperature, and the pistons and cylinders are identical. The cylinders in Cases A and C contain nitrogen, and the cylinders in Cases B and D contain helium, which has fewer grams per mole. The volume of gas is the same for Cases A and B, and the same for Cases C and D.



Rank the pressures of the gases in the cylinders.

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

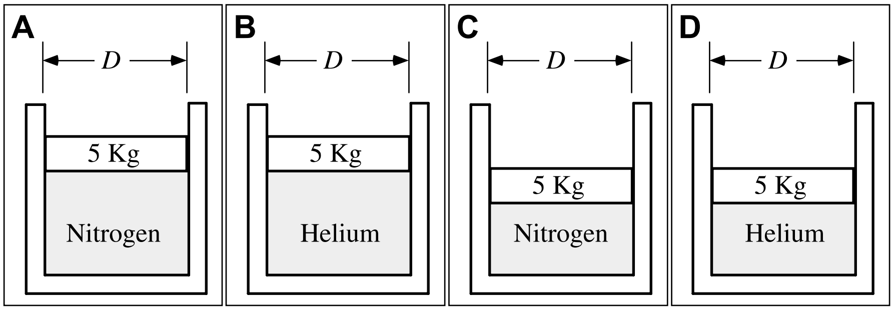
Explain your reasoning.

Answer: All the same.

There is no net force on the pistons, since the pistons are at rest. The force on the piston by the gas is *therefore equal to the weight of the piston, which is the same in all cases. The pressure of the gas is the force divided by the area over which the force acts, or the area of the bottom surface of the piston. This area is the same in all cases, so the pressure must be the same for all of the gases.*

C3-RT30: IDEAL GASES IN CYLINDERS WITH A PISTON—NUMBER OF MOLES

Each cylinder contains an ideal gas trapped by a piston that is free to move without friction. The pistons are at rest. All gases are at the same temperature, and the pistons and cylinders are identical. The cylinders in Cases A and C contain nitrogen, and the cylinders in Cases B and D contain helium, which has fewer grams per mole. The volume of gas is the same for Cases A and B, and the same for Cases C and D.



Rank the number of moles of gas in the cylinders.

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

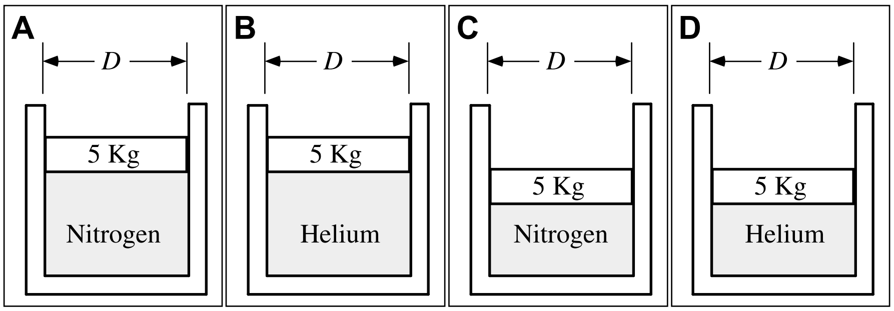
Explain your reasoning.

Answer: A = B > C = D.

Using the ideal gas law the number of moles is proportional to the product of the pressure and volume divided by the temperature. There is no net force on the pistons, since the pistons are at rest. The force on the piston by the gas is therefore equal to the weight of the piston, which is the same in all cases. The pressure of the gas is the force divided by the area over which the force acts, or the area of the bottom surface of the piston. This area is the same in all cases, so the pressure must be the same for all of the gases. Since the pressure and temperature are the same for each case, the number of moles (from the ideal gas law) must be proportional to the volume of the gas (Since $pV = nRT$, $n = pV/RT$). The volume of gas is the same for cases A and B, and smaller and the same for cases C and D.

C3-RT31: IDEAL GASES IN CYLINDERS WITH A PISTON—TEMPERATURE

Each cylinder contains an ideal gas trapped by a piston that is free to move without friction. The pistons are at rest. All gases are at the same temperature, and each cylinder contains the same number of moles of gas. The pistons and cylinders are identical. The cylinders in Cases A and C contain nitrogen, and the cylinders in Cases B and D contain helium, which has fewer grams per mole. The volume of gas is the same for Cases A and B, and the same for Cases C and D.



Rank the temperature of the gas in the cylinders.

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

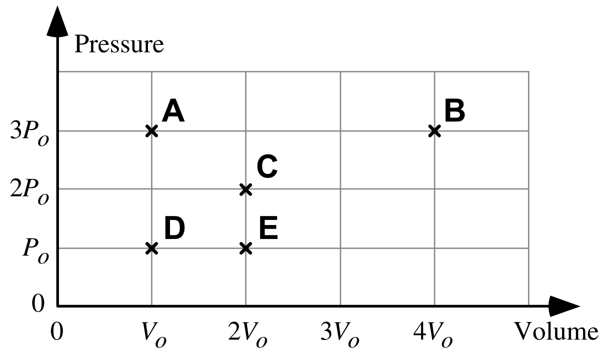
Explain your reasoning.

Answer: A = B > C = D.

Using the ideal gas law the temperature is proportional to the product of the pressure and volume divided by the number of moles. There is no net force on the pistons, since the pistons are at rest. The force on the piston by the gas is therefore equal to the weight of the piston, which is the same in all cases. The pressure of the gas is the force divided by the area over which the force acts, or the area of the bottom surface of the piston. This area is the same in all cases, so the pressure must be the same for all of the gases. Since the pressure, temperature, and number of moles are the same for each case, the temperature (from the ideal gas law) must be proportional to the volume of the gas (Since $pV = nRT$, $T = pV/nR$). The volume of gas is the same for cases A and B, and smaller and the same for cases C and D.

C3-RT32: PRESSURE-VOLUME GRAPH I—TEMPERATURE IN DIFFERENT STATES

Five points representing five different states of one mole of an ideal gas are labeled on the pressure–volume graph below.



Rank the temperatures of the ideal gas in the labeled states.

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

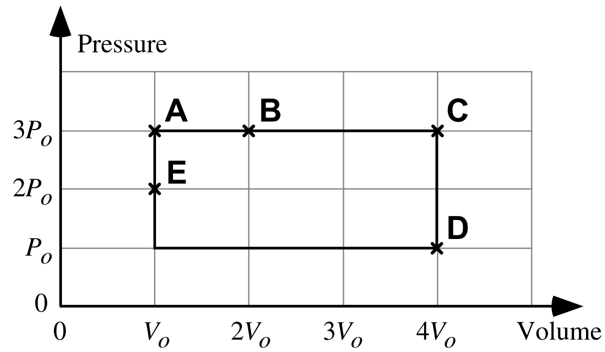
Explain your reasoning.

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

As prescribed in the Ideal Gas Law the temperature in each state is proportional to the product of the pressure and volume in that state since the amount of gas, one mole, is fixed throughout. Here PV = 12 P_oV_o for state B, 4 P_oV_o for state C, 3 P_oV_o for state A, 2 P_oV_o for state E, and P_oV_o for state D.

C3-RT33: PRESSURE-VOLUME GRAPH II—TEMPERATURE IN DIFFERENT STATES

Five points representing five different states of one mole of an ideal gas are labeled on the pressure–volume graph below.



Rank the temperatures of the ideal gas in the labeled states.

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

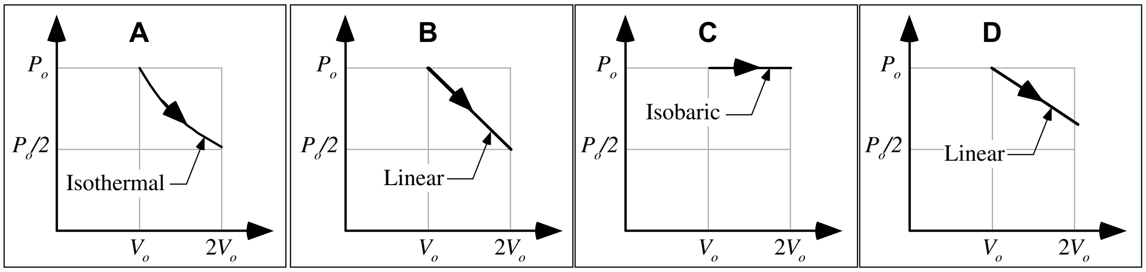
Explain your reasoning.

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

By the Ideal Gas Law the temperature is proportional to the product of the pressure and volume for each state, since the amount of gas is fixed at one mole. Here $PV = 12P_oV_o$ for state C, $6P_oV_o$ for state B, $4P_oV_o$ for state D, $3P_oV_o$ for state A, and $2P_oV_o$ for state E.

C3-RT34: THERMODYNAMIC IDEAL GAS PROCESSES—FINAL TEMPERATURE

Four thermodynamic processes are illustrated below. These processes are for the same ideal gas starting in the same state (same pressure, volume, temperature, and amount of gas) and ending at the same final volume that is twice the initial volume.



Rank the final temperature of the gas in these processes.

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

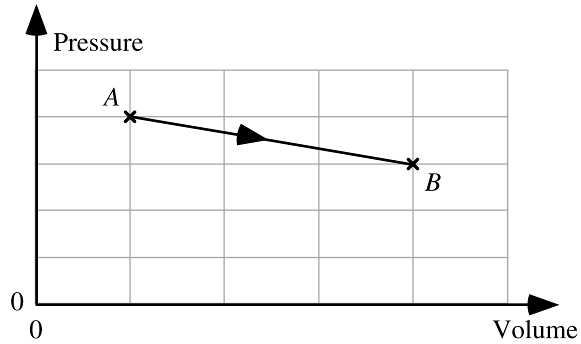
Explain your reasoning.

Answer: C > D > A = B.

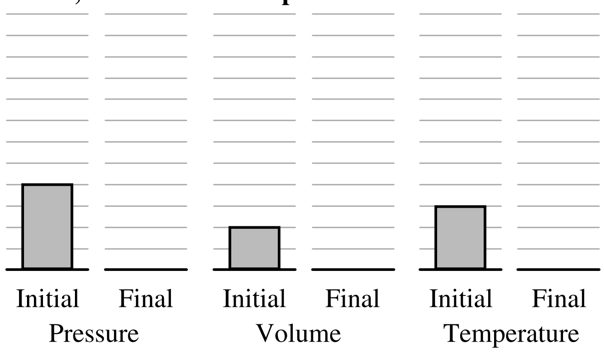
The temperature T is proportional to PV using the ideal gas law. The temperature does not change for A and B, because the product PV is the same in the final state as in the intial state. The temperature increases in cases C and D, but since both have the same final volume and the pressure is higher in case C than in case D, the temperature is also higher in C than in D.

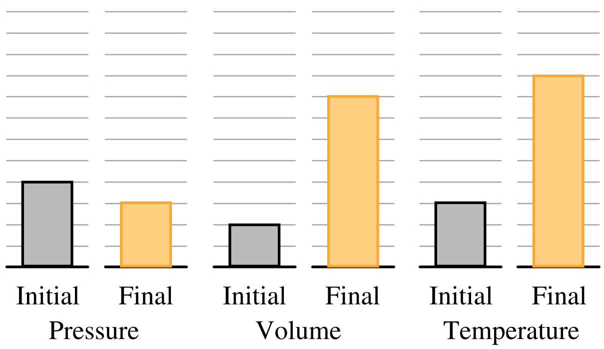
C3-CRT35: PRESSURE-VOLUME GRAPH—PRESSURE, VOLUME, AND TEMPERATURE BAR CHARTS

An ideal gas trapped in a cylinder expands while its pressure drops. The starting point for this process is labeled *A* and the endpoint is labeled *B* in the graph of pressure versus volume.



This initial pressure, volume, and temperature are shown in the histograms. Complete the histograms, showing the final pressure, volume, and absolute temperature.



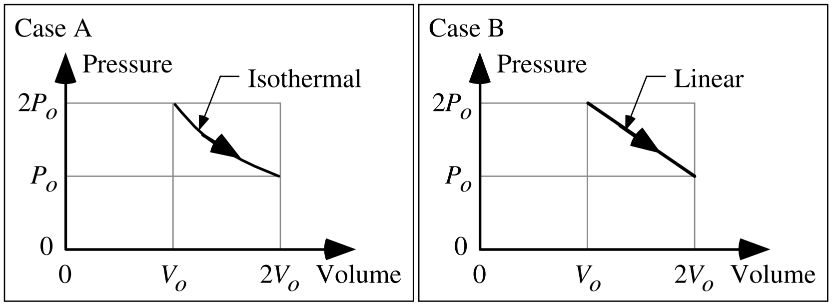


Explain your reasoning.

Answer: We can read from the graph that the pressure decreases to three-quarters of its initial value, and the volume increases to 4 times its initial value. From the ideal gas law, the product of pressure and volume will be proportional to the absolute temperature, so the final temperature will be greater than the initial temperature by a factor of 3.

C3-CT36: PRESSURE–VOLUME GRAPHS FOR EXPANDING GAS—WORK DONE

Two containers of the same number of moles of an ideal gas are taken from the same initial state (same pressure, volume, and temperature) to the same final state by two different paths, as shown.



Is the work done by the gas on its surroundings (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

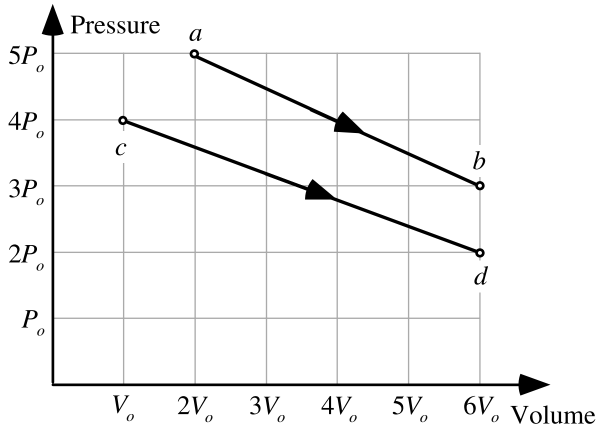
Explain your reasoning.

Answer: (ii) Greater in case B.

The work done by the gas on the surroundings is equal to the area under the pV curve. This area is greater in case B than in case A.

C3-WWT37: PRESSURE–VOLUME GRAPH FOR TWO PROCESSES—CHANGE IN TEMPERATURE

Two processes $a \Rightarrow b$ and $c \Rightarrow d$ are shown on the pressure versus volume graph. A sample of an ideal gas is expanded using process $a \Rightarrow b$, and an identical sample is expanded using process $c \Rightarrow d$.



A student trying to decide which gas has the greatest change in temperature states:

"The change in pressure is the same for both processes, and the change in volume is greater for process c⇒ d. So the change in temperature must be greater for process c⇒ d."

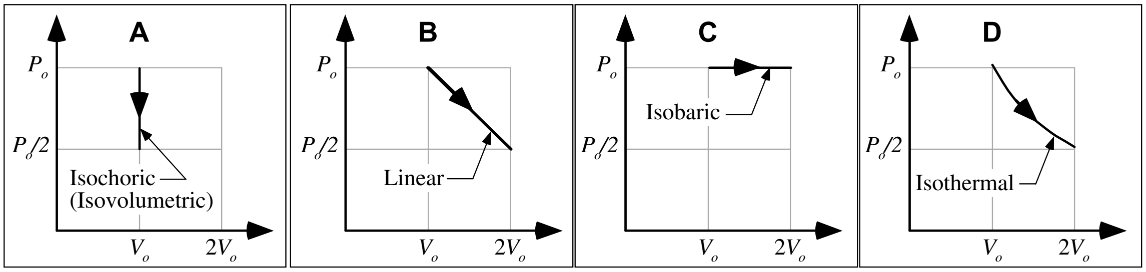
What, if anything, is wrong with the student's contention? If something is wrong, identify it and explain how to correct it. If nothing is wrong, explain the physics behind the student's answer.

Answer: The student is not correct.

The change in temperature will equal the final temperature minus the initial temperature, and using the ideal gas law this is $p_f V_f/nR - p_i V_i/nR$, which is proportional to $p_f V_f - p_i V_i$. The student is considering the differences of the pressure and the volume separately, but the temperature change is determined by the difference of the product of pressure and volume. For process a ⇒ b, this difference is $18p_o V_o - 10p_o V_o = 8p_o V_o$, and for process c ⇒ d, this difference is $12p_o V_o - 4p_o V_o = 8p_o V_o$. The temperature difference is the same for both processes.

C3-RT38: PRESSURE–VOLUME GRAPHS FOR VARIOUS PROCESSES—WORK DONE BY GAS

In each case, the same ideal gas undergoes a thermodynamic process starting in the same state (same pressure, volume, temperature, and amount of gas). The final equilibrium states are different for each case.



Rank the amount of work that is done by the gas on the environment for the process shown in each case.

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

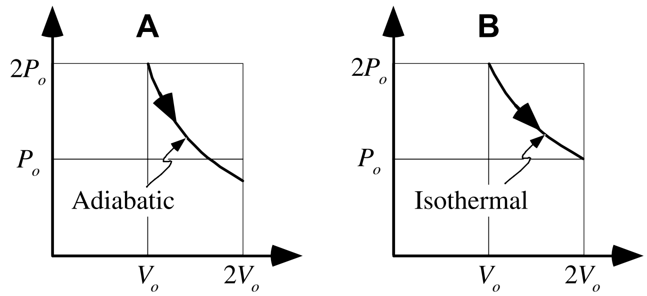
Explain your reasoning.

Answer: C > B > D > A.

In case A the volume of the gas does not change so no work is done. For the other three cases the volume of the gas increases, so the gas does positive work on its surroundings. The amount of work is equal to the area under the line or curve representing each process.

C3-CT39: ISOTHERMAL AND ADIABATIC IDEAL GAS PROCESSES—WORK, HEAT, AND TEMPERATURE

In both cases below, one mole of an ideal gas is expanded from an initial volume V_o to a final volume 2 V_o. In both cases, the gas is identical and the initial pressure is $2P_o$. The expansion is adiabatic in A and isothermal in B.



(a) Will the final temperature of the gas 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 final pressure is less for the adiabatic process than for the isothermal process. Since T is proportional to PV and the final volume is the same, the final temperature will be proportional to the final pressure.

(b) Will the work done by the gas 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 area under the PV curve is the work done by the gas, and is greater in case B.

(c) Will the heat exchanged by the gas with its surroundings be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

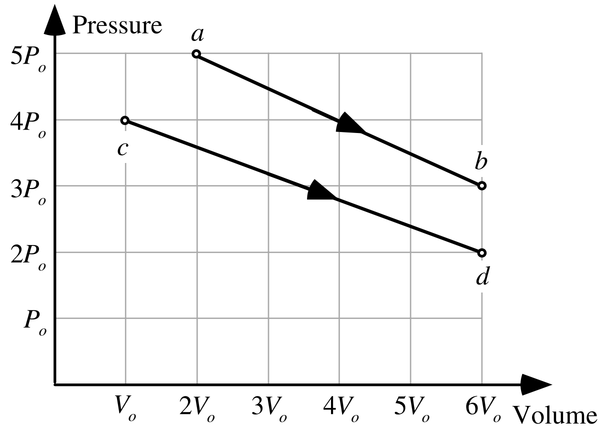
Explain your reasoning.

Answer: (ii) greater in case B.

An adiabatic process is one in which there is no heat exchanged between the system and its surroundings.

C3-CT40: PRESSURE–VOLUME GRAPH FOR PROCESSES—WORK DONE

Two processes $a \Rightarrow b$ and $c \Rightarrow d$ are shown on the pressure versus volume graph. A sample of an ideal gas is expanded using process $a \Rightarrow b$, and an identical sample is expanded using process $c \Rightarrow d$.



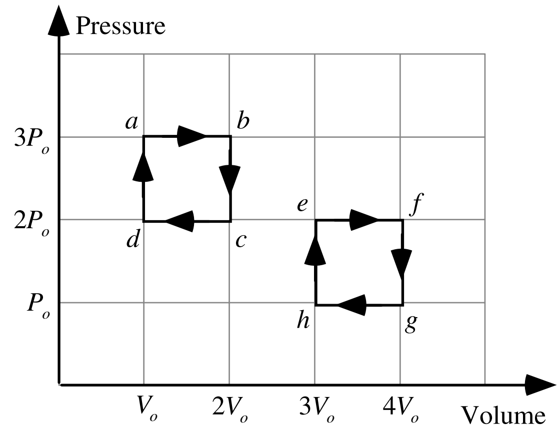
Is the work done by the gas in process a ⇒ b (i) *greater than*, (ii) *less than*, or (iii) *the same as* the work done by the gas in process c ⇒ d? _____
Explain your reasoning.

Answer: (ii) less than.

The area under the line is related to the work done.

C3-CT41: PRESSURE–VOLUME GRAPH FOR VARIOUS PROCESSES—WORK

An ideal gas is trapped in a cylinder with a piston. Eight states of the gas are labeled *a–h*, and eight processes between these states are shown as solid lines with arrows.



(a) Is work done by the gas for the process *a* ⇒ *b* (i) *greater than*, (ii) *less than*, or (iii) *equal to* the work done by the gas for the process *e* ⇒ *f*? _____

Explain your reasoning.

Answer: (i) greater than.

Work equals pΔV, and while ΔV is the same for both processes the pressure is greater for the process from a to b.

(b) Is work done by the gas for the process *b* ⇒ *c* (i) *greater than*, (ii) *less than*, or (iii) *equal to* the work done by the gas for the process *f* ⇒ *g*? _____

Explain your reasoning.

Answer: (iii) equal to.

Both are zero, since there is no change in volume there is no displacement, so the work is zero.

(c) Is work done by the gas for the process *a* ⇒ *b* ⇒ *c* ⇒ *d* (i) *greater than*, (ii) *less than*, or (iii) *equal to* the work done by the gas for the process *e* ⇒ *f* ⇒ *g* ⇒ *h*? _____

Explain your reasoning.

Answer: (iii) equal to.

The work done by the gas for each cycle is equal to the area within the cycle, and those areas are the same.

(d) Is total work done by the gas for the cyclic process *a* ⇒ *b* ⇒ *c* ⇒ *d* ⇒ *a* (i) *greater than*, (ii) *less than,* or (iii) *equal to* the total work done by the gas for the process *e* ⇒ *f* ⇒ *g* ⇒ *h* ⇒ *e*? _____

Explain your reasoning.

Answer: (iii) equal to.

The total work for each cycle is equal to the area within the cycle, and those areas are the same.

C3-LMCT42: CARNOT HEAT ENGINE I—EFFICIENCY

A Carnot heat engine operating between 727 °C and 127 °C takes in 2,000 J from the hot reservoir and exhausts 800 J to the cold reservoir.

Identify from choices (i)–(iv) how each change (a) to (e) described below will affect the efficiency of the heat engine as compared to the initial efficiency.

This change will cause the *efficiency* of this Carnot heat engine:

(i) to ***increase***.
(ii) to ***decrease***.
(iii) to *remain the* ***same***.
(iv) to be ***indeterminate***.

All of these modifications are individual changes to the initial situation.

(a) The temperature of the hot reservoir (727 °C) is increased. _____
Explain your reasoning.
Answer: (i) ***increase.***

The efficiency of the Carnot cycle depends on the ratio of the temperature of the cold reservoir to the hot reservoir, i.e., Eff = 1 - T_C/T_H. The smaller this ratio the higher the efficiency, so increasing the temperature of the hot reservoir will make the ratio smaller.

(b) The temperature of the cooler reservoir (127 °C) is increased. _____
Explain your reasoning.
Answer: (ii) ***decrease.***

Increasing the temperature of the cold reservoir will make the ratio larger, decreasing the efficiency.

(c) Energy taken into the engine (2000 J) is increased. _____
Explain your reasoning.
Answer: (iii) ***remain the same.***

The efficiency depends on the temperatures of the two reservoirs only.

(d) The temperatures of the hot reservoir and cool reservoir are increased by the same amount. _____
Explain your reasoning.
Answer: (ii) ***decrease.***

This pair of changes will make the ratio larger, decreasing the efficiency.

(e) The temperature of the hot reservoir is increased while the temperature of the cool reservoir is decreased by the same amount. _____
Explain your reasoning.
Answer: (i) ***increase.***

This will make the fraction T_C/T_H smaller and thus increase the efficiency.

C3-WWT43: CARNOT ENGINE II—EFFICIENCY

A newly designed engine operating between 727 °C and 127 °C takes in 5,000 J from the hot reservoir and exhausts 1,000 J at the lower temperature. A student states:

"This is a great new engine. The efficiency of a Carnot engine is 82.5% between those temperatures using $(T_h - T_c)/T_h$*, but this new engine has an efficiency of 80%, which is pretty close to the best possible Carnot engine between those temperatures."*

What, if anything, is wrong with this student's contention? If something is wrong, identify it and explain how to correct it. If nothing is wrong, explain why the statement is valid.

Answer: The student's contention is wrong

He/she did not use the absolute temperatures of 1000 K and 400 K when they computed the efficiency.

C3-SCT44: CARNOT ENGINE III—EFFICIENCY

A Carnot engine operating between 727 °C and 127 °C takes in 1,000 J from a hot reservoir. Students are discussing the efficiency of this engine:

Albert: *"The efficiency of this engine is 82.5% using $(T_h\text{-}T_c)/T_h$ and it does not depend on how much energy is taken from the hot reservoir."*

Ben: *"Using $(T_h\text{-}T_c)/T_h$ is the right way to go, but the temperatures have to be in K so the efficiency of this engine is 60%."*

Connie: *"The efficiency of this engine is 80.6% using $(T_h\text{-}T_c)/T_h$ after converting the temperatures to Fahrenheit (°F)."*

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

Albert _____ Ben _____ Connie _____ None of them_____

Explain your reasoning.

Answer: Ben is correct.

The temperatures have to be expressed in Kelvin when using this relation.