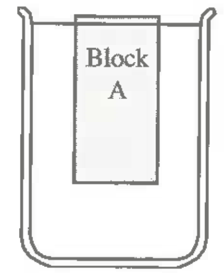
IV. Sinking and floating

A. A rectangular block, A, is released from rest at the center of a beaker of water. The block accelerates upward.

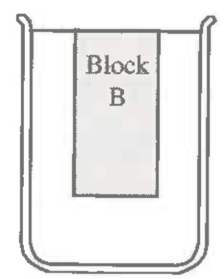
1. At the instant it is released, is the buoyant force on block A *greater than, less than,* or *equal to* its weight? Explain.



2. When block A reaches the surface, it is observed to float at rest as shown. In this final position, is the buoyant force on the block *greater than, less than,* or *equal to* the weight of the block? (*Hint:* What is the net force on the object?)

3. Are your answers to the questions above consistent with Archimedes' principle? (*Hint:* How does the volume of water displaced when the block is floating compare to that displaced when it was completely submerged?)

B. A second block, B, of the same size and shape as A but slightly greater mass is released from rest at the center of the beaker. The final position of this block is shown at right.



How does the buoyant force on block B compare to the buoyant force on block A:

- at the instant they are released? Explain.

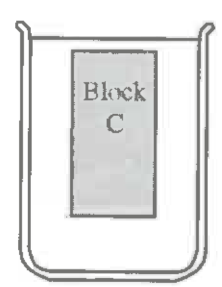
- at their final positions? Explain.

C. A third block, C, of the same size and shape as A and B but with slightly greater mass than block B is released from rest at the center of the beaker. Two students predict the final position of the block and draw the sketch at right.

Student 1: *Since this block is heavier than block B, it will not go up as high after it is released, as shown at right.*

Student 2: *Yes, I agree, the buoyant force is slightly less than the weight of this block, so it should come to rest a bit below the surface.*

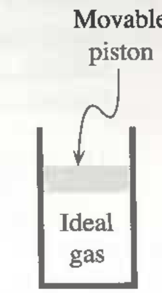
Explain what is *wrong* with each statement and with the diagram.



Student drawing

I. Pressure

A cylinder contains an ideal gas that is at room temperature. The cylinder is sealed with a piston of mass M and cross-sectional area A that is free to move up or down without friction. No gas can enter or leave the cylinder. The piston is at rest. Atmospheric pressure (*i.e.*, the pressure of the air surrounding the cylinder) is P_o.



A. In the space provided, draw a free-body diagram for the piston.

Make sure the label for each force indicates:

- the type of force,
- the object on which the force is exerted, and
- the object exerting the force.

Free-body diagram for piston

B. In the space provided, draw an arrow to indicate the direction of the net force on the piston. If the net force is zero, state so explicitly.

Net force on piston

C. Is the force exerted on the piston by the gas *inside* the cylinder *greater than, less than,* or *equal to* the force exerted on the piston by the air *outside* the cylinder? Explain.

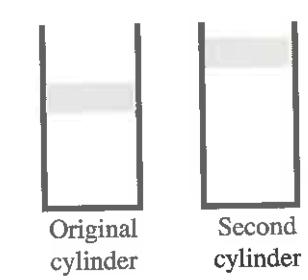
Write an equation that relates all the forces on your free-body diagram. (*Hint:* How are these forces related to the net force?)

D. Is the pressure of the gas in the cylinder *greater than, less than,* or *equal to* atmospheric pressure? Explain.

Determine the value of the pressure of the gas in the cylinder in terms of the given quantities. (*Hint:* Which of the forces that act on the piston can you use to find the pressure of the gas?)

E. A second cylinder contains a different sample of ideal gas at room temperature, as shown at right. The two cylinders and their pistons are identical.

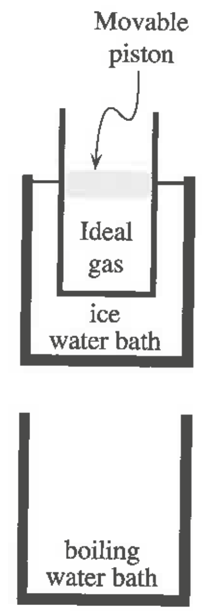
Is the pressure of the gas in the second cylinder *greater than, less than,* or *equal to* the pressure in the cylinder above? If you cannot tell, state so explicitly. Explain.



➪ Check your answer with a tutorial instructor before you continue.

II. Pressure and temperature

A. A cylinder of the type described in section I contains a fixed amount of gas. Initially, it is in thermal equilibrium with an ice-water bath. The pressure, volume, and temperature of the gas are $P_{initial}$, $V_{initial}$, and $T_{initial}$, respectively.



The cylinder is then removed from the ice water and placed into boiling water. After the system has come to thermal equilibrium with the boiling water the pressure, volume, and temperature are P_{final}, V_{final}, and T_{final}.

1. Is T_{final} *greater than, less than,* or *equal to* $T_{initial}$?

2. Is P_{final} *greater than, less than,* or *equal to* $P_{initial}$? Explain.

   Is your answer consistent with your answer to part D of section I? If not, resolve any inconsistencies.

3. Is V_{final} *greater than, less than,* or *equal to* $V_{initial}$? Explain.

   Is your answer consistent with the ideal gas law (*i.e.*, the relationship $PV = nRT$)? If not, resolve any inconsistencies.

B. In the process you considered in part A above, which variables are held constant and which are allowed to change? Explain how you can tell.

C. Consider the following student dialogue.

Student 1: *"According to the ideal gas law, the pressure is proportional to the temperature. Since I increased the temperature of the gas, the pressure must go up."*

Student 2: *"That's right. Since no gas entered or left the system, the volume did not change. So the pressure must have increased."*

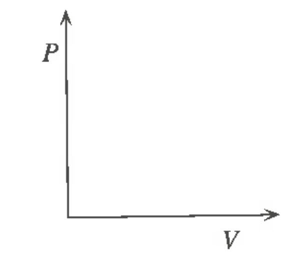
Do you agree with either of the students? Explain your reasoning.

➪ Check your reasoning with a tutorial instructor before you continue.

III. *PV* diagrams

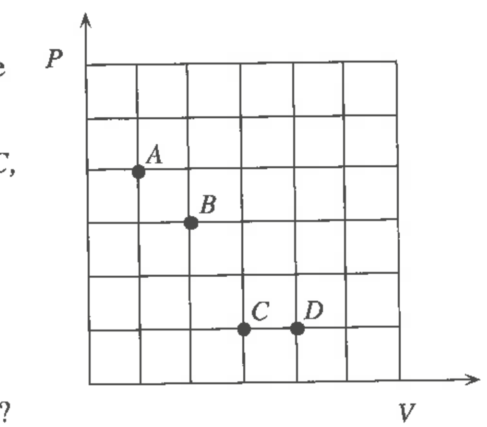
Ideal gas processes are often represented graphically. For instance, a *PV diagram* is a graph of pressure *versus* volume for a given sample of gas. A single point on the graph represents simultaneously measured values of pressure and volume. These values define a *state* of the gas.

A. Sketch the process described in section II on the *PV* diagram provided. Label the initial and final states of the gas.



Is your sketch consistent with your answer in part B of section II? Explain.

B. The same sample of ideal gas is used for a new experiment. The pressure and volume of the gas are measured at several times. The values of *P* and *V* are recorded on the diagram shown at right.



1. Rank the temperatures of the gas in states *A*, *B*, *C*, and *D* from largest to smallest. If any two temperatures are the same, state so explicitly.

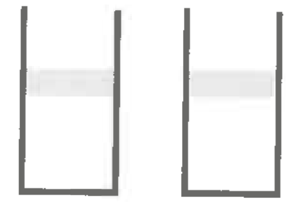
2. Is your ranking consistent with the ideal gas law?

3. Is it possible for the gas to be in a state in which it has the same volume as in state *B* and the same temperature as in state *A*? If so, mark the location of the state on the *PV* diagram. If not, explain why not.

➪ Check your reasoning with a tutorial instructor before you continue.

IV. Avogadro's number

A. Two identical cylinders of the type described above contain hydrogen and oxygen, respectively. Both cylinders have been in the same room for a long time. Their pistons are at the same height.



Hydrogen Oxygen

1. Compare the volumes of the gases in the two cylinders. Explain.

2. Compare the temperatures of the gases in the two cylinders. Explain.

3. Compare the pressures in the two cylinders. Explain.

4. Compare the number of moles in the two cylinders. Explain.

   Is your answer consistent with the ideal gas law?

B. A student looks up the molar masses and finds the values 2 g (for H_2) and 32 g (for O_2).

1. Give an *interpretation* of these two numbers. (*Note:* A formula is not considered an interpretation.)

2. Compare the masses of the gas samples in the two containers. Explain.

C. Consider the following student discussion.

Student 1: *"Since hydrogen molecules are so much smaller than oxygen molecules, there should be more of them in the same volume."*

Student 2: *"No, since n = 2 for hydrogen, and n = 32 for oxygen, there must be more oxygen molecules."*

Find the flaws in the statements of both students. Explain.

➪ Check your reasoning with a tutorial instructor.

I. Work

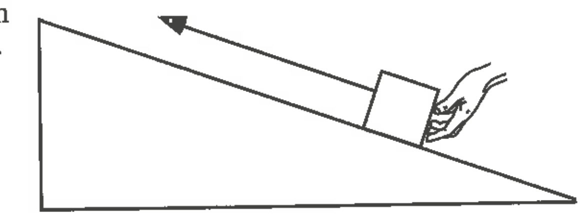
A. Recall the definition of work done on an object by an agent that exerts a force on that object. (You may wish to consult your textbook.)

In the spaces provided, sketch arrows representing (1) a force exerted on an object and (2) the displacement of that object for cases in which the work done by the agent is:

Positive	Negative	Zero

In each case, does your sketch represent the *only* possible relative directions of the force and displacement vectors? If so, explain. If not, sketch at least one other possible set of vectors.

B. A block is pushed by a hand as it moves from the bottom to the top of a frictionless incline. The block is speeding up at a constant rate.

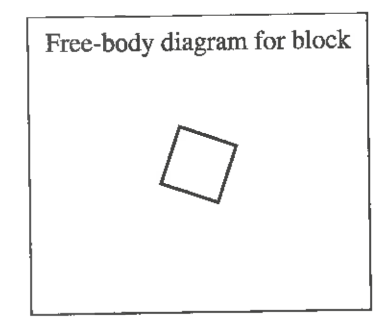


Frictionless incline

1. In the space provided, draw a free-body diagram for the block.

   Make sure the label for each force indicates:

   - the type of force,
   - the object on which the force is exerted, and
   - the object exerting the force.



2. In the space provided, draw an arrow to show the direction of the net force on the block.

Net force on block

3. State whether the following quantities are *positive, negative,* or *zero*. In each case, explain your reasoning.

   - the work done on the block by the *hand*
   - the work done on the block by the *Earth*
   - the work done on the block by the *incline*

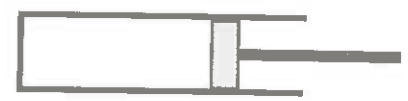
4. Is there work done on the hand by the block in this motion? If so, is this work *positive, negative,* or *zero?* Explain.

5. The *work-kinetic energy theorem* states that the change in kinetic energy of a rigid body is equal to the net work done on that body. Explain how your answers to part 3 are consistent with this theorem. (*Hint:* The *net work* is the sum of the works done by all forces exerted on an object.)

6. Which, if any of your answers in part 3 would be different if the block were being pushed up the incline with constant speed?

   Describe the net work done on the block in that case.

C. An ideal gas is contained in a cylinder that is fixed in place. The cylinder is closed by a piston as shown in the diagram at right. There is no friction between the piston and the cylinder walls.



1. Describe the direction of the force that the piston exerts on the gas.

   Does your answer depend on whether the piston is moving?

2. How could the piston move so that the work it does on the gas is:

   - positive?
   - negative?

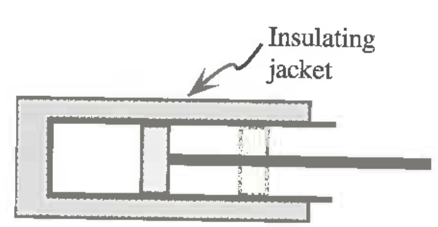
   Do your answers depend on your choice of coordinate system?

3. In each of the two cases in part 2, is there work done on the piston by the gas? If so, how is that work related to the work done on the gas by the piston? (Consider both sign and absolute value.)

➪ Check your answers with a tutorial instructor before you continue.

II. Work and internal energy

A. Imagine that the cylinder from section I is thermally isolated from its surroundings by placing it in an insulating jacket. The piston is pressed inward to the position shown at right. We will refer to this compression as process 1.



Is the work done on the gas by the piston *positive, negative,* or *zero?*

In thermal physics, we are often interested in the *internal energy* (E_{int}) of a system. The internal energy of an ideal gas is proportional to the temperature and the number of moles of the gas. The internal energy can change when energy is exchanged with the system's environment (*e.g.*, objects that are outside the system of interest). The case above is one in which the internal energy of a gas changes due to work done on the gas (the system) by the piston (an agent external to the system). When such a system is thermally isolated, the change in internal energy of the system is equal to the net work done on it:

$$\Delta E_{int} = W_{on\ system} \qquad \text{(for a thermally isolated system)}$$

B. 1. Does the internal energy of a gas in an insulated cylinder *increase, decrease,* or *remain the same* when the piston is pushed inward? Explain.

2. Does the temperature of the gas change? Explain.

C. Two students are discussing process 1:

   Student 1: *"The volume of the gas decreases, but the pressure increases. Therefore, by the ideal gas law, the temperature must remain the same."*

   Student 2: *"But I know the temperature goes up. The volume is less, and therefore the particles collide more often with one another."*

   Neither student is correct. Find the flaws in the reasoning of each student. Explain.

➪ Check your reasoning with a tutorial instructor before you continue.

III. Heat

A. Imagine that the cylinder from section II is no longer thermally insulated, and the piston is locked in place. The gas is initially at room temperature.

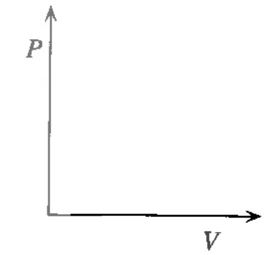
   The cylinder is then placed into boiling water and reaches thermal equilibrium with the water. We refer to this process as process 2.

   1. In process 2, do the following quantities *increase, decrease,* or *remain the same?* Explain.

      - the temperature of the gas
      - the internal energy of the gas
      - the pressure of the gas
      - the volume of the gas

2. Sketch process 2 on the *PV* diagram at right.

3. Is there any work done on the gas in process 2? Explain. Is your answer consistent with your *PV* diagram?



The energy transfer that takes place in this process is called *heat transfer*. In this process, if the heat transferred to the gas *(Q)* is greater than zero, the internal energy of the gas will increase.

B. In process 2, is the heat transfer to the gas *positive, negative, or zero?* Explain.

C. In process 2, is the heat transfer to the boiling water *positive, negative, or zero?* Explain.

IV. Heat, work, and internal energy

The *first law of thermodynamics* states that the change in internal energy of a closed system is equal to the sum of the net work done on the system and the heat transferred to the system:

$$\Delta E_{int} = Q + W_{on\ system}$$

A. Explain how you could write this law in terms of the work done *by* the system on its environment.

How does your textbook express the first law of thermodynamics?

B. In process 1 (section II) you did not need to consider heat transfer. What feature of the experiment prevented heat transfer to the gas?

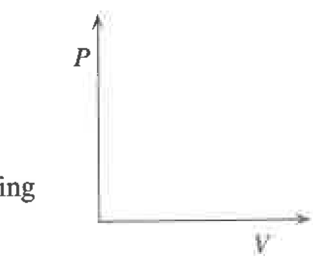
C. In process 2 (section III) you did not need to consider work. What feature of the experiment prevented work from being done on the gas?

➪ Check your reasoning with a tutorial instructor before you continue.

D. The cylinder, with the piston still locked in place, is now immersed in a mixture of ice and water and allowed to come to thermal equilibrium with the mixture. The piston is then moved inward very slowly, in such a way that the gas is always in thermal equilibrium with the ice-water mixture. We will refer to this slow compression of the gas as process 3.

1. In process 3, do the following quantities *increase, decrease,* or *remain the same?* Explain.
   - the volume of the gas
   - the temperature of the gas
   - the internal energy of the gas
   - the pressure of the gas

2. Sketch process 3 on the *PV* diagram provided.



3. Determine whether the following quantities are *positive, negative,* or *zero:*
   - the work done on the gas in process 3 (Explain your reasoning by referring to a force and a displacement.)
   - the heat transfer to the gas in process 3

4. Are your answers above consistent with the first law of thermodynamics? Explain.

E. How does the compression in process 3 differ from the compression in process 1? Explain.

F. A student is considering process 3:

"The temperature doesn't change; it is an isothermal process. Therefore, the heat transfer must be zero."

Do you agree with this student? Explain.