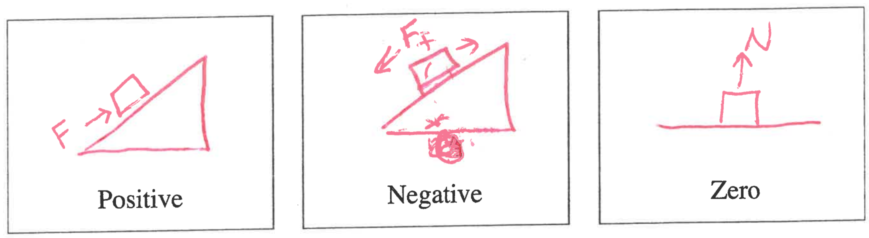
I. Work

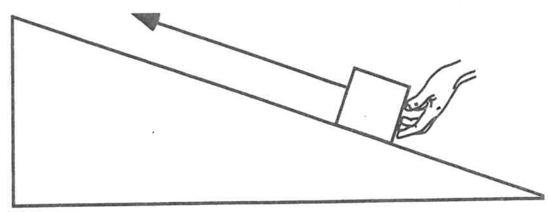
A. Recall the definition of work done on an object by an agent that exerts a force on that object. (You may wish to consult your textbook.)

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:



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.

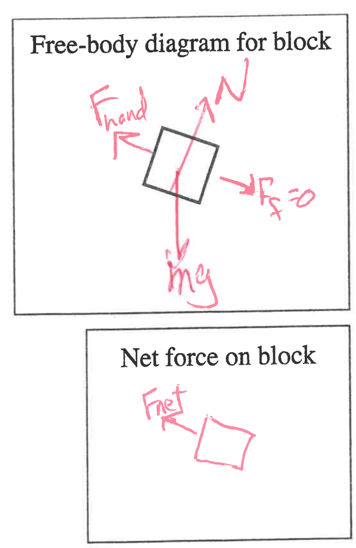

Frictionless incline

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.



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*

     0

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.)

   $W_{net} > 0$ and thus $\Delta K > 0$

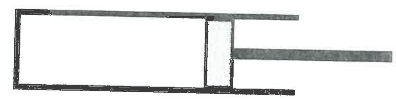
6. Which, if any of your answers in part 3 would be different if the block were being pushed up the incline with constant speed?

   They'd have the same signs as before

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

   $W_{net} = 0$

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?

   no, there's always an equal-and-opposite force to the pressure

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

   - positive? $-x$
   - negative? $+x$

   Do your answers depend on your choice of coordinate system?

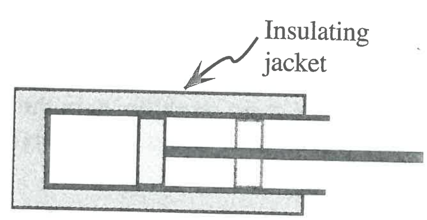
   no

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.) equal and opposite

⇨ 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:

and the negative sign disappears

$$\Delta E_{int} = W_{on\ system}$$ Q=0 (for a thermally isolated system) since the subscript ha flipped to "on 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.

increase

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

yes

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.

#1 ●U increases so T increases #2 needs to also address the P

➪ 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.

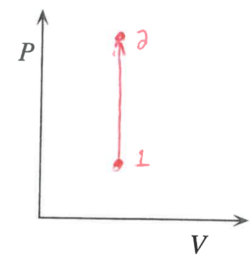
1. In process 2, do the following quantities *increase, decrease,* or *remain the same?* Explain.

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

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?

   no $\Delta V = 0$



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.

   positive

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

   negative conservation of energy

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:

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

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

   $\Delta U = Q - W$

   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?

   ~~the work done by the piston~~ the insulation

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?

   locked piston

➪ 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.

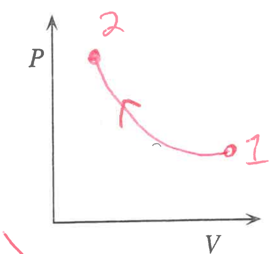
   - the volume of the gas   decrease

   - the temperature of the gas   same

   - the internal energy of the gas   same

   - the pressure of the gas   increase

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.)

     positive (negative by the gas)

   - the heat transfer to the gas in process 3

     negative $Q = \Delta U + W_{by} \rightarrow Q = +W_{by} < 0$

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.

   #1: $Q = 0$ #3: $\Delta U = 0$

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.

   $Q = W_{by} < 0$