# Workshop Tutorials for Introductory Physics

# Solutions to TI4: **First Law of Thermodynamics**

## A. Review of Basic Ideas:

**Conservation of Energy and the First Law of Thermodynamics**

Conservation of Energy is one of the most useful and widely used concepts in **physics**. You may have seen the concept of conservation of energy in the study of motion (mechanics), but often with a qualifying statement - providing the effects of **friction** can be ignored. The first law of thermodynamics is a statement of conservation of energy that includes any flow of **thermal** energy in or out of a system. It establishes Conservation of Energy as a central principle in physics.

To discuss the flow of energy in or out of a system we first have to define the system we are talking about. A system may or may not be an isolated system. An **isolated** system is one where no energy flows in or out of the system. Consider the situation where Brent and **Rebecca** are sitting on the beach with the cool box of drinks. The cool box is not an isolated system as thermal energy flows in. Consider the system of the earth plus cool box. Since energy flows to the earth from the **sun** this system is not isolated either. One of the essential skills of a physicist is to be able to judge which features of a situation are essential to solving a problem and which features are not really significant. It may be that a system can be treated as an isolated system when the flow of energy is very **small**.

The First Law of Thermodynamics states that any change in **internal** energy, $\Delta U$, of a system is equal to the sum of the work done on the system and the heat flow into the system. Mathematically it can be written $\Delta U = Q + W$, where the work, $W$, is **positive** when work is done on the system and the heat, $Q$, is positive when heat flows **into** the system.

In the example of the cool box the increase in internal energy is due to the flow of thermal energy into the cool box. No **work** is being done on the cool box. So $\boldsymbol{\Delta U = Q}$. Pumping bicycle tyres is another example. Here we are compressing the gas as we pump and so work is being done on the gas. If we do it quickly the thermal energy has no time to flow out and the internal energy of the gas increases. This is an example of an adiabatic process, where $\boldsymbol{\Delta U = W}$.

## B. Activity Questions:

### 1. Bicycle pump

The air in the sealed off pump is compressed quickly, hence work is done on the air. There is little time for heat transfer to occur, so $Q \sim 0$, and the change undergone by the gas is a good approximation to an adiabatic process. The increase in internal energy is indicated by the rise in temperature, which is detected by a thermocouple inside the pump.

### 2. Ball bearings in a tube

When you shake the tube you do work on the ball bearings and give them kinetic energy.
The kinetic energy is lost as thermal energy as the ball bearings settle again, and this thermal energy increases the temperature of the ball bearings.
You could heat up a coffee this way, but it would take years of vigorous shaking!

### 3. Heat and Work

There are three processes: in the first system, the piston is pushed down into the insulated cylinder. This is adiabatic, as the insulation prevents heat exchange. In the second system, the gas inside the tin is heated with the lid on. This is isochoric – the volume is kept constant. In the third system the gas is heated with the sliding lid on, and a load on top – this is isobaric as the weight on top of the lid keeps the pressure constant.

| | process 1 | process 2 | process 3 |
|---|---|---|---|
| Heat (+ is in) | 0 | + | + |
| Work (+ is out) | - | 0 | + |
| $\Delta U$ | + | + | + |

## C. Qualitative Questions.

**1.** Consider the human body as a system and apply the first law of thermodynamics to it..

**a.** Internal energy is related to temperature. The human body has fairly constant temperature, hence the internal energy does not decrease as described above.

**b.** Internal energy is added to the body to balance the continual decrease due to heat flow from the body and work being done by the body. The added internal energy comes from food. The food is broken down into simple components like sugars which are stored, then when the body needs energy the sugar is broken down and oxidized (has oxygen added), and there is energy released.

**c.** We gain energy from the food, air and water that we take in. This energy is converted to heat and into work, and stored as potential energy, for example in fats. The total energy is always conserved, and the change in internal energy is the difference between the energy gained and the energy lost as heat and work.

**2.** Brent comes home and finds Rebecca sitting in front of the fridge with the door open.

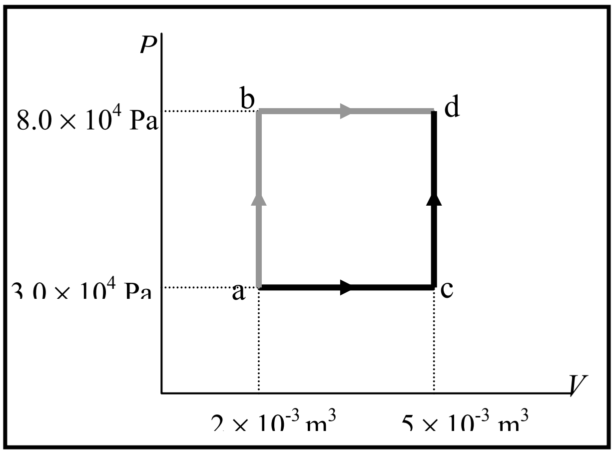
**a.** The temperature of the room will increase if Rebecca leaves the fridge door open. Energy is required to "move" the heat from the inside of the fridge to the coils at the back of the fridge. The energy comes from the electricity used to run the fridge, and the process is not perfectly efficient, some of the energy is lost as heat (for example due to resistance in the wiring). Even if the process was 100% efficient, the temperature would not drop because the total energy would be conserved, although directly in front of the door might be a little cooler than near the back of the fridge.

**b.** An icebox full of ice would help to cool the flat. Thermal energy from the air is used to melt the ice, the amount of energy required is called the latent heat of transformation. So the air will lose energy to melt the ice, thus cooling the air.

**a.** An air conditioner keeps a room cool without violating the first law of thermodynamics. It moves heat from the inside of a house to the outside. To do this uses energy. An air conditioner always has one side poking out of the house where hot air is pumped out, or a duct going to the outside.

## D. Quantitative questions.

A series of thermodynamic processes is shown in the pV-diagram below. In process ab, 150 J of heat are added to the system, and in process bd, 600 J of heat are added.




**a.** The internal energy change in process ab must be 150 J because the work done is zero (no volume change) so $\Delta U_{ab} = Q_{ab}$.

**b.** In process bd the pressure is constant so the work done is

$W_{\mathrm{bd}} = p(V_d - V_b)$

$=(8.0\times10^4 \text{ Pa})\ (5.0\times10^{-3} \text{ m}^3 - 2.0\times10^{-3} \text{ m}^3) = 240 \text{ J}$

We know from **a** that the work done in process ab is zero, so the total work in process abd is

$W_{abd} = W_{\mathrm{bd}} + W_{\mathrm{ab}} = 240 \text{ J} + 0 \text{ J} = 240\text{J}$

The total heat added is

$Q_{abd} = Q_{ab} + Q_{bd} = 150 \text{ J} + 600 \text{ J} = 750 \text{ J}.$

The change in internal energy is the heat added minus the work done, which is

$\Delta U_{abd} = Q_{abd} - W_{abd} = 750 \text{ J} - 240 \text{ J} = 510 \text{ J}.$

**c.** The change in internal energy, $\Delta U$ is independent of path, so $\Delta U_{acd} = \Delta U_{abd} = 510$ J.

The total work for path acd is

$W_{acd} = W_{\mathrm{ac}} + W_{\mathrm{cd}} = p(V_c - V_a) + 0 = (3.0\times10^4 \text{ Pa})\ (5.0\times10^{-3} \text{ m}^3 - 2.0\times10^{-3} \text{ m}^3) = 90 \text{ J}.$

The heat added is

$Q_{acd} = \Delta U_{acd} + W_{acd} = 510 \text{ J} + 90 \text{ J} = 600 \text{ J}.$ This is quite different to process abd.