Heat, work and internal energy (in animals)

- Heat and work are the two ways in which energy is transferred between a system and its environment (the systems with which it can interact).

- All animals do *work* and loose heat. This work is done in
  - swimming
  - crawling
  - walking
  - flying
  - pumping blood through blood vessels

- Heat is lost from the skin and lungs by convection (evaporation), conduction, and radiation

- The conservation of energy principle requires that all of this energy be at the expense of *internal energy*

- The *internal energy* of a system is the sum of all the energies (KE + PE) of all the atoms or molecules in the system

- Animals must replenish this internal energy by eating

- Metabolism is the set of chemical reactions through which food is converted into energy in the cells of organisms

The First Law of Thermodynamics

The first law is really an energy accounting principle. The energy contained in a system is its internal energy. Heat that flows into the system increases its internal energy, while heat that flows out decreases its internal energy. Systems can also do work or have work done on them. When a system does work, its internal energy decreases. If work is done on a system, its internal energy increases. The energy balance (*bottom line*) between what goes into a system (as heat or work) and what goes out (as heat or work) is expressed as the 1^{st} Law.

Suppose an amount of heat Q flows into a system, while the system does an amount of work W, the *change in the internal energy of the system ΔU* is then

$$\Delta U = Q - W$$

First Law of Thermodynamics

You can make an analogy with your bank account balance:

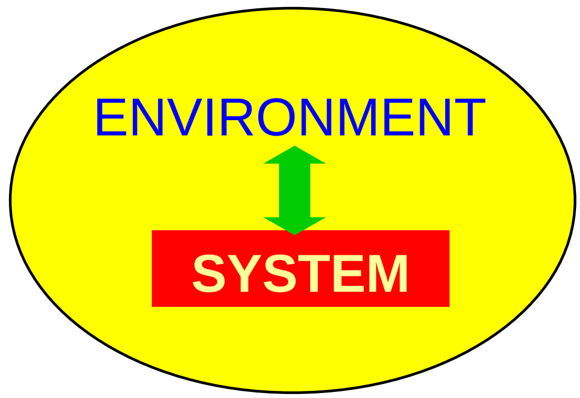
The change in your account balance

= deposits ($'s in) – withdrawals ($'s out)

1) The first law of thermodynamics is a constraint on how a system exchanges energy (heat and work) with other systems in its environment.

2) In general, a system can interact with all other systems in the universe. The other systems that it interacts with are called its environment.

3) In a more practical sense, the system and its environment are *isolated* so that only energy transfers between the system and the environment need to be considered.



4) The *general conservation of energy principle* states that the energy in the Universe is constant.

5) This means that the any change in the energy of the system must be offset by an equal and opposite energy change in the environment, i.e., $\Delta U_{environment} + \Delta U_{system} = 0$

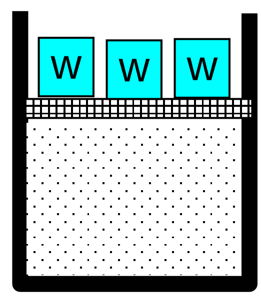
6) We use an ideal monatomic gas as a model system to illustrate how the first law works. Why? Because the ideal monatomic gas is relatively simple, we know how its macroscopic parameters are related to each other:

- $PV = nRT$ (ideal gas law)
- the internal energy depends only on n and T:

$$U = \frac{3}{2}nRT$$

7) We can also find the work done by the gas or on the gas.

8) Consider an ideal gas in a sealed container with a lid (*area A*) that can move up or down. The parameters of the gas are P, V, n, T, and the internal energy U(T).



9) We consider first the case in which the gas is insulated so that no heat can enter or leave the system (this is called an *adiabatic process*)

10) The gas can do work by expanding, or work could be done on it if it is compressed.

11) The gas is in mechanical equilibrium: The gas exerts an upward force (PA) on the lid due to its pressure, and this upward force is balanced by the downward force due to the weight of the lid and the weights placed on top of it, as well as the downward force due to atmospheric pressure.

12) Imagine now that one of the weights is removed. The gas will then expand, lifting the lid and remaining weights (performing work), until a new equilibrium is established.

13) Suppose the gas exerts a force PA on the lid and lifts it by a distance Δs, thus performing work $W = (PA)\ \Delta s$.

14) $PA\ \Delta s = \Delta V$, the change in volume of the gas, so

$\mathbf{W = P\ \Delta V = P(V_f - V_i)}$ → this is the work done when a gas expands or is compressed. (We can imagine compressing the gas by adding more weights to the lid.) Notice that if $V_f > V_i$, $W > 0$, meaning that the *gas does work*, while if $V_f < V_i$, $W < 0$, meaning that *work is done on the gas*.

15) What does the first law tell us now about how the properties of the gas change when work is done by the gas or on the gas?

16) Since no heat enters or leaves the gas, the first law says that

$\mathbf{\Delta U = -W = -P\ \Delta V}$.

(a) If the gas does work (expands) $\mathbf{\Delta V > 0, W > 0,}$ so that $\mathbf{\Delta U < 0}$ → $U_f < U_i$. Since $U = (3/2)\ n\ R\ T$, the change in U is -- $\mathbf{\Delta U = n\ R\ \Delta T}$ → $\mathbf{\Delta T < 0}$ → the gas cools.

(b) If the gas is compressed by adding weights to the lid, then work is done on the gas, $W < 0$, so $\Delta U = -W > 0$, and $\Delta T > 0$, so the gas heats up.

17) Internal energy change.—Since no heat enters or leaves the gas during these processes, the work done by or on the gas results directly in a change in the internal energy of the gas.

(a) when the gas does work and no heat is added to it, the work is done at the expense of its internal energy

(b) when work is done on the gas by compressing it, its internal energy increases