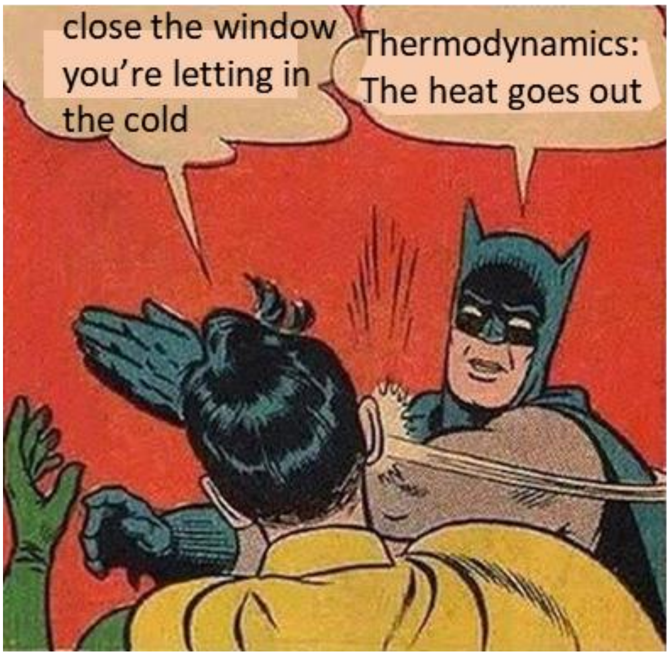
VISUAL PHYSICS ONLINE

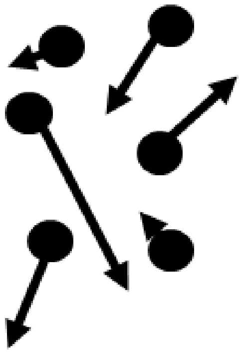
THERMODYNAMICS

THERMAL ENERGY

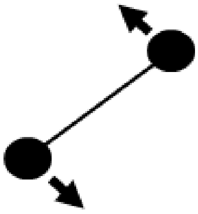


INTERNAL ENERGY

A thermodynamic System is composed of molecules in a solid state and/or a liquid and/or a gas state. The molecules always have some **random** or **chaotic motion**. Therefore, the System has a kinetic energy due to this random and chaotic motion. The kinetic energy is classified as **translational kinetic energy** (movement of molecules from one place to another), **rotational kinetic energy** (rotation of molecules about the XYZ axes) and **vibrational kinetic energy** (periodic vibrations of the molecules).



translational K.E.



rotational K.E.

vibrational K.E.

There are attractive and repulsive forces acting between molecules often giving rise to molecular bonds. Therefore, the System has **potential energy** due to these interactions.

The total sum of all the kinetic energies of the molecules together with the potential energies of the System is called the **internal energy** $E_{\text{int}} \equiv U$ of the System. It is a state variable and its value can change with time in response to the exchange of energy between the System and the surrounding environment through the processes of **work** W and **heat** Q.

Often **internal energy** is also called **thermal energy**. However, sometimes, thermal energy has a much broader interpretation. Even physicist can’t agree on the language to be used in thermal physics. The best approach is to consider the internal energy as the sum of the kinetic energies and potential energies for the System and use thermal energy as a broader term that is closely related to internal energy.

INTERNAL ENERGY U [joule J]

$$U = \sum \underbrace{KE}_{\text{Random chaotic motion}} + \sum \underbrace{PE}_{\text{interaction between atoms \& molecules}}$$

Value of U not important, ΔU during a thermal process is what matters

$$\boxed{\Delta U = U_2 - U_1 = U_{final} - U_{initial}}$$

The **system** is the coffee.
The **internal energy** of the coffee decreases with time as energy is transferred from the hot System to the cooler surrounding environment.

$$T_{coffee} > T_{environment}$$

Heat or heat transfer Q is the energy transferred to or from a System due to a difference in temperature between the System and its environment. The direction of the transfer is always from hot to cold.

The internal energy of an isolated system is constant. Internal energy is **not** a form of energy but a way of describing the fact that the energy in atoms is both stored as potential and kinetic energy. It does **not** include kinetic energy of the object as a whole or any external potential energy due to actions of external forces or relativistic energy $\left(E = mc^2\right)$.

But what do we mean by heat, work and temperature?

Temperature T [K kelvin]

Macroscopic view:

The temperature of a System is the degree of hotness or coldness of the System as measured on a temperature scale using a thermometer.

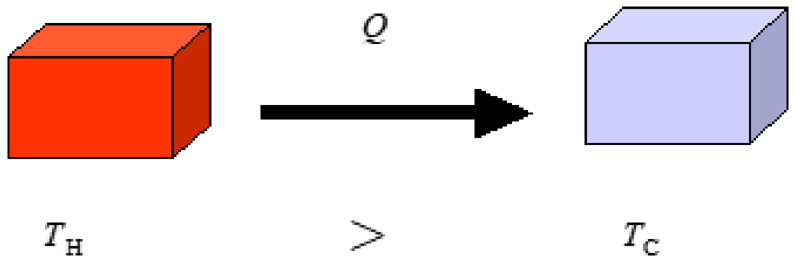
Microscopic view:

Temperature of a system is a measure of the random chaotic translational kinetic energy of the particles of the System.

Heat Q [J joule]

Heat transfer can be considered both the amount of energy transferred as well as the process itself as a result of a temperature difference.

Heat refers to the amount of energy exchanged between Systems due to their difference in temperature. Heat is not a property of a System (heat is not a state variable and not a function of time). It is often better to use **heat transfer** rather than the single word heat.



Spontaneous transfer of energy

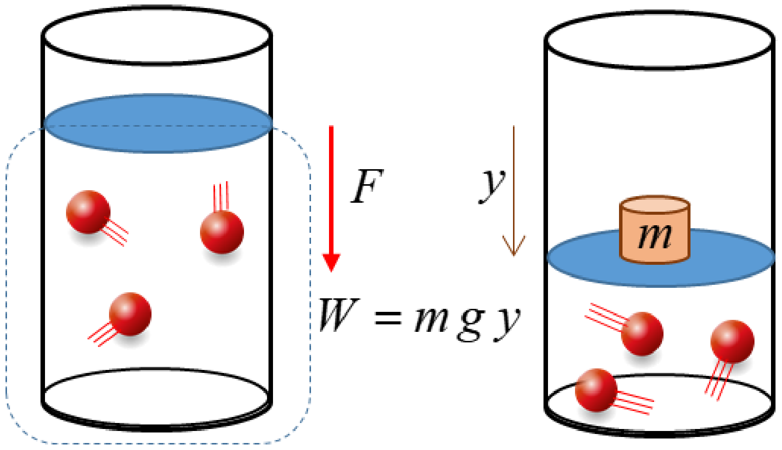
At one time it was though – erroneously – that an object contained a certain amount of “heat fluid” that could flow from one place to another. This idea was overturned by the observations of Benjamin Thompson (Count Rumford). He observed that as long as mechanical work was done to turn drill bits in the boring of cannons, they continued to produce unlimited quantities. Heat could not be contained in the metal cannons, but was continually produced by the turning drill bit.

Work W [J joule]

When a force causes a displacement, we say that work is done on or by the System. The energy transferred to or from a System by work may cause a change in temperature of the System.

Example: When a gas is compressed in a cylinder, the energy of the gas may result in an increase in the temperature of the gas.

System: gas inside cylinder



translational kinetic energy of molecules increased $\Rightarrow$ increase in temperature of System

Example: if you rub your hands together, you do work. The energy associated with that work is not lost; instead, it produces an increase in the random, chaotic motion of the translational motions of the skin molecules which means that the temperature of the skin will increase. In the process of rubbing your hands, we can account for all the energies and we find that **energy is conserved**. No observation has been made in a situation in which energy is not conserved.

You do work in rubbing your hands together – where does the energy go?

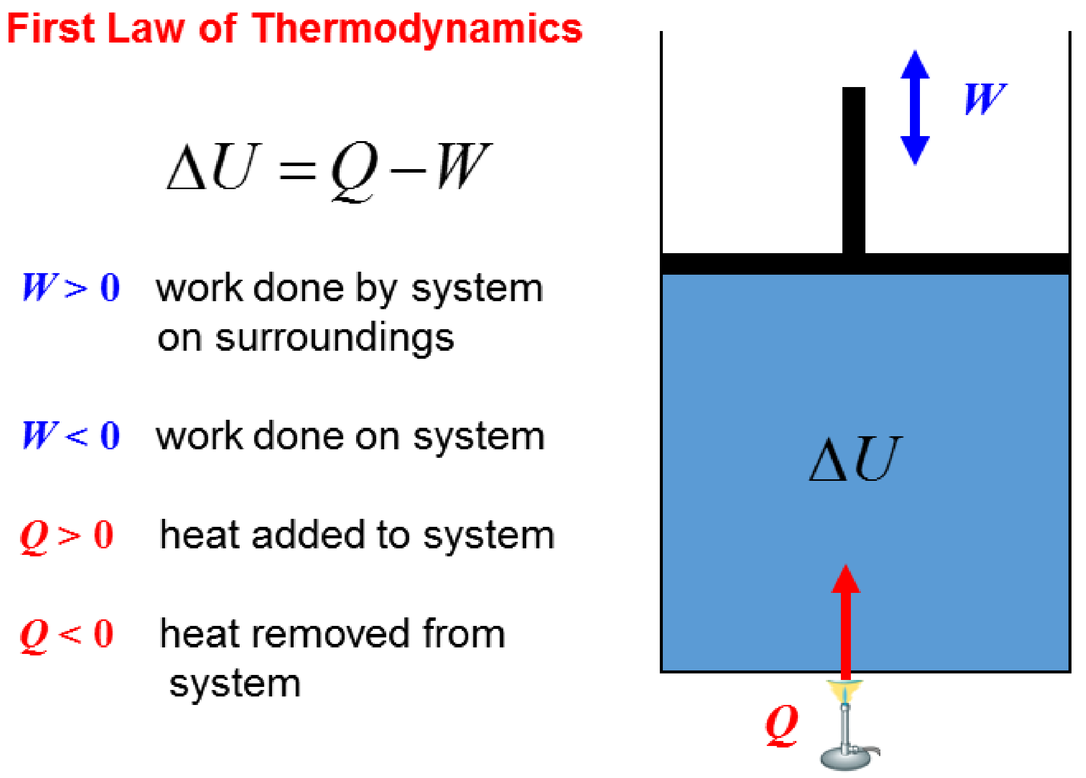
FIRST LAW OF THERMODYNAMICS

The **First Law of Thermodynamics** is a statement of **energy conservation** that specifically includes heat transfer (heat) and work.

If heat Q is transferred to a System, the internal energy E_{int} increases. If this System does work W on the surrounding environment, this energy must come from the internal energy E_{int} of that System.

The **First law of Thermodynamics** (a law of conservation of energy) is

$$\Delta E_{\text{int}} = Q - W \qquad \textbf{First Law of thermodynamics}$$



First Law of Thermodynamics

$$\Delta U = Q - W$$

$W > 0$ work done by system on surroundings

$W < 0$ work done on system

$Q > 0$ heat added to system

$Q < 0$ heat removed from system

Example

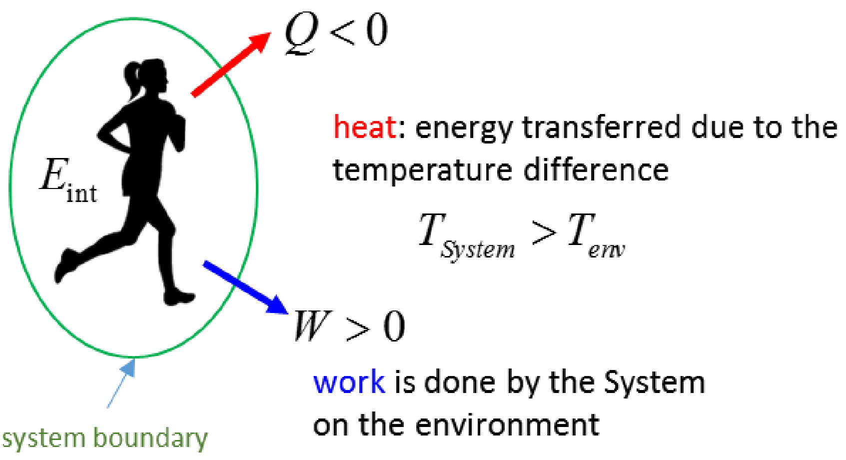
Running along the beach on the weekend, you do 4.8x10^5 J of work and give off 3.7x10^5 J of heat. (a) What is the change in your internal energy? (b) When walking, you give off 1.5x10^5 J of heat and your internal energy decreases by 2.3x10^5 J. How much work have you done whilst walking?

Solution

The person is the System

Apply the First Law of Thermodynamics $\Delta E_{\text{int}} = Q - W$

Draw an animated scientific diagram



heat: energy transferred due to the temperature difference

$$T_{System} > T_{env}$$

work is done by the System on the environment

(a)

$$W = 4.8 \times 10^5 \text{ J} \quad Q = -3.7 \times 10^5 \text{ J} \quad \Delta E_{\text{int}} = ? \text{ J}$$

$$\Delta E_{\text{int}} = Q - W = -8.5 \times 10^5 \text{ J}$$

(b)

$$W = ? \text{ J} \quad Q = -1.5 \times 10^5 \text{ J} \quad \Delta E_{\text{int}} = -2.3 \times 10^5 \text{ J}$$

$$\Delta E_{\text{int}} = Q - W$$

$$W = Q - \Delta E_{\text{int}} = +0.8 \times 10^5 \text{ J}$$

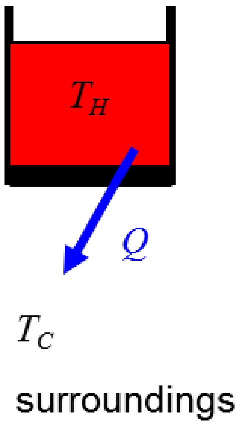
The internal energy E_{int} is a very different quantity to heat Q and work W. Heat Q is the amount of energy exchanged because of a temperature difference between Systems when in thermal contact or a System and its surrounding environment. Work W indicates a transfer of energy by the action of a force through a distance. The internal energy E_{int} is a state variable that depends on time and upon the state of the System and not how it was brought to that state.

Example

Consider a hot cup of coffee sitting on a table as the System. Using this System as an illustration, give a scientific interpretation of the terms: temperature, heat, work, internal energy, thermal equilibrium.

Solution

Identify / Setup



temperature T **(K)**

heat Q **(J)**

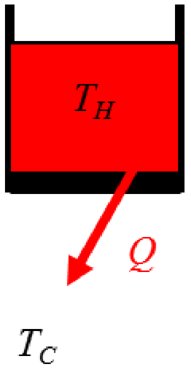
work W **(J)**

internal energy U **(J)**

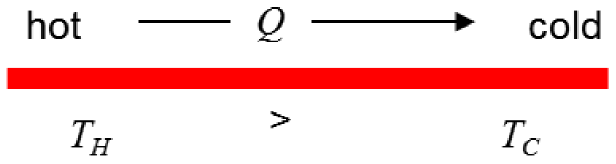
thermal equilibrium

0th law 1st law 2nd law

2. Execute



(i) **Temperature** T – measure of hot/cold as determined by a temperature scale



(ii) **Heat** Q energy transferred spontaneously due to a temperature difference (hot to cold) *2nd Law*

(iii) **Work** W $\boxed{W = \int_{V_1}^{V_2} p\, dV}$

Change in volume of coffee is negligible $\Rightarrow$ $W = 0$

(iv) Internal Energy U

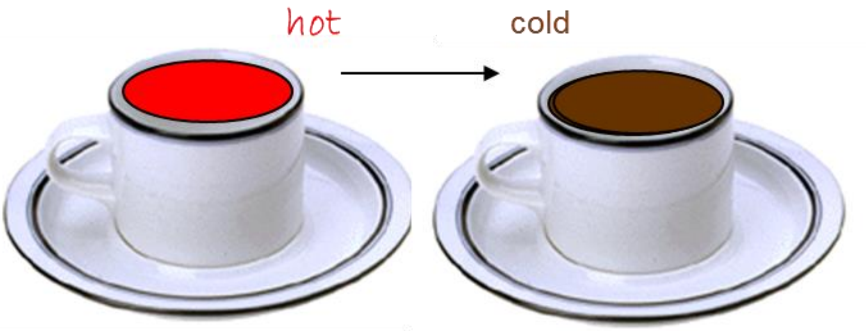
$$U = \underbrace{\sum KE}_{\text{Random chaotic motion}} + \underbrace{\sum PE}_{\text{interaction between atoms \& molecules}}$$

1st Law: Conservation of energy – transfer of energy by work W and heat Q between thermodynamic system and surrounding environment gives a change in internal energy $\Delta U = Q - W$

Heat is transferred to surroundings from the coffee, giving a decrease in the coffee's internal energy: $W = 0,\ Q < 0 \Rightarrow \Delta U < 0$ **(decrease in temperature)**

(v) The temperature of the coffee decreases until it is in **thermal equilibrium** with the surroundings

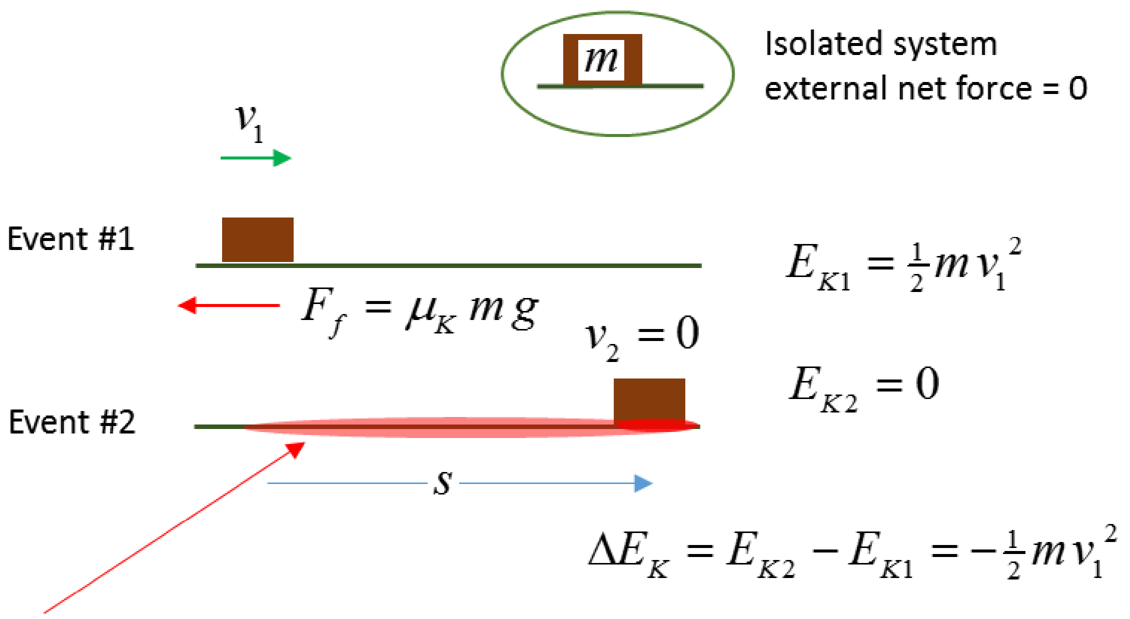
$T_{coffee} = T_{surroundings}$ *0th Law*



CONSERVATION OF ENERGY INVOLVING FRICTION

Consider a block that is given an initial velocity v_1 on a horizontal surface. The block comes to a stop due to the frictional force acting on it (coefficient of kinetic friction μ_K). Let the System be the (block + surface). The external net force acting on the System is zero, therefore, we have an isolated System.

System: block + surface



Temperature of System increases because of work and friction

Since we have an isolated System there is zero transfer of energy into or out of the System. Since energy cannot be created or destroyed, where did the decrease in energy (kinetic) of the System go?

The decrease in energy (kinetic) of the System shows up as an increase in the internal energy of the (block + surface) System and the temperature of the system will increase.

$$\Delta E_{\text{int}} = Q - W$$

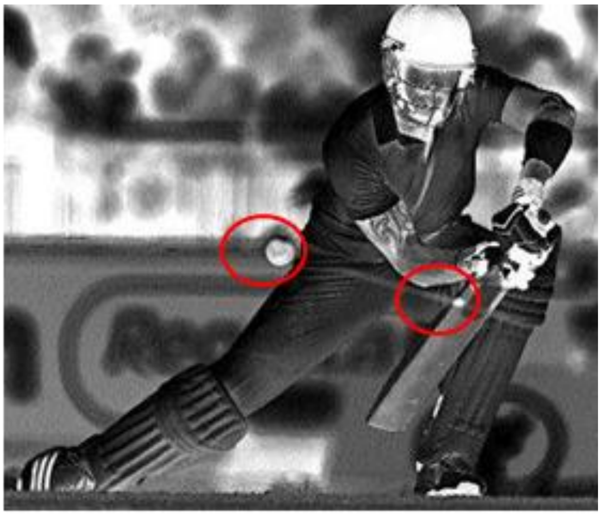
$$Q = 0$$

$$W = \Delta E_K = E_{K2} - E_{K1} = -\tfrac{1}{2} m v_1^{\,2} = -F_f\, s$$

$$\Delta E_{\text{int}} = \tfrac{1}{2} m v_1^{\,2} = F_f\, s$$

The temperature of the System increases without any heat input. The temperature rise comes from friction and work.

A very good example of an increase in temperature of an object without heating is when a cricket ball is struck by a bat. During the impact of bat and ball, kinetic energy is lost and the internal energy of both bat and ball increase, therefore, the temperature at the impact points of bat and ball increases. This is shown clearly in the thermal imaging of the impact of bat and ball. The image in cricketing terms is called “**hot spot**”. All objects because of their temperature, emit electromagnetic radiation (mainly infrared), the hotter the surface the more radiation is emitted at shorter wavelengths.



METHODS OF HEAT TRANSFER

Heat can be exchanged in a variety of ways. The Sun, for example, warms us from across 149.6 million km by a process known as **radiation**. As sunlight is absorbed by the ground its temperature increases, the air near the ground gets warmer and begins to rise, producing a further exchange of energy by **convection**. As you walk across the hot ground in bare feet, you feel a warming effect as heat enters your body by **conduction**. In the following units, we look further into the processes of

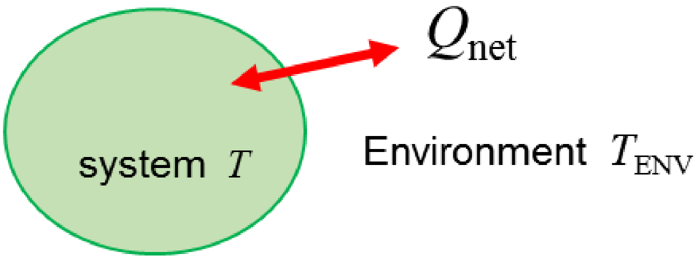
radiation **convection** **conduction**

heat Q is the energy transfer due to a temperature difference ΔT

CONDUCTION

CONVECTION

RADIATION



Q_{net}

system T

Environment T_{ENV}

European heat wave, 2003 ⇒ ~35 000 deaths in France

Thinking Questions

How are the methods of heat transfer related to the live sheep trade?

Live sheep trade

Sunday, October 26, 2003

Sheep to shore ... finally

The Labor Opposition will pursue the Government over the cost of the "ship of death" saga, which ended on Friday when 50,000 Australian sheep at sea for three months began being unloading in Eritrea.

Identify all the methods of heat transfer from the two images

VISUAL PHYSICS ONLINE

If you have any feedback, comments, suggestions or corrections please email:

Ian Cooper   School of Physics   University of Sydney
ian.cooper@sydney.edu.au