THERMAL ENERGY AND OTHER TYPES OF INTERNAL ENERGY

1] FRICTION AND THERMAL ENERGY

- Until this section, <u>*all mechanics is based on the model of object as a single material point*</u>. In reality, the objects are constituted by *atoms* (*or molecules*) which "***interact*** *between them and* ***move*** *inside the object"* and this means some "***energy inside the object*** ". The *atoms* (*or molecules*) are ***strongly bound*** *to each other* inside a ***solid***, ***slightly bound*** *between them* inside a ***liquid*** and they are ***free*** (not bound) inside a ***gaz***. But, no matter what is the physical state of object, its *atoms* (*or molecules*) are in a ***continuous random motion***. This type of motion is characterized by an ***average speed*** and this means a kind of ***kinetic energy inside the object***. The ***temperature*** of the object is a <u>*macroscopic parameter*</u> related to the ***average kinetic energy*** of atoms (or *molecules***)** inside it. When this type of kinetic energy increases, the *temperature of object increases and vice versa*. One has labelled as ***thermal energy*** "$\mathbf{E_{th}}$" the amount of energy related to this *random motion* of microscopic particles ***inside an object***.
Next, one derives the *principle of energy conservation* for a *system* constituted by <u>*objects with microscopic structure*</u> , i.e. a system that contains **thermal energy**.

-One may easily realise (*just by rubbing hands*) that two bodies that rub on each other produce heat. This *heat* <u>***increases***</u> the <u>***thermal energy***</u> E_{th} of the two bodies (*hands get warm*). Precise measurements have shown that the *increase* of *thermal energy* ***of*** the two bodies is equal to the ***magnitude*** of work by friction.

$$\Delta E_{th}\ (>0) = -W_f = -(-f_k * d) = f_k * d \qquad (1)$$

If the kinetic ***friction*** is one of external ***forces*** acting on the ***system***, one may separate the work by friction at expression of mechanical energy conservation principle and get $\mathbf{W_{ext\_net} = W_{ext} + W_f = \Delta E_{mech}}$ (2)

Then, $\mathbf{W_{ext} = \Delta E_{mech} - W_f = \Delta E_{mech} + \Delta E_{th}}$ and rewrite the principle of energy conservation as

$$\mathbf{W_{ext} = \Delta E_{mech} + \Delta E_{th}} \qquad (3)$$

-Note that W_{ext} in this expression <u>*does not include the work by friction*</u>. So, the ***external work*** <u>*without friction work*</u> ***goes*** for the ***change*** of ***total mechanic energy*** of the system **and** the ***change*** of the ***thermal energies*** of the ***system*** $\Delta E_{th\text{-}sys}$ ***and*** *that of the* ***external objects*** $\Delta E_{th\text{-}obj}$ ***in contact*** *with system parts* (fig.1).

$$\mathbf{\Delta E_{th} = \Delta E_{th\text{-}sys} + \Delta E_{th\text{-}obj}} \qquad (4)$$

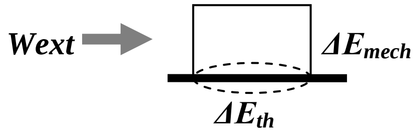


Fig.1

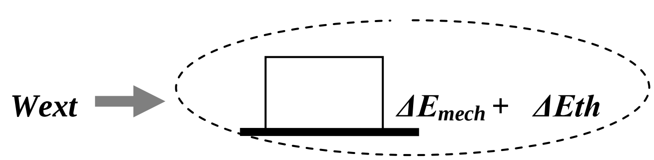
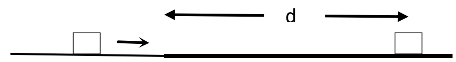


Fig 2

One may include into system the "*adjacent objects affected by friction"* and make the friction an ***internal*** <u>***but***</u> ***non-conservative*** force of system (fig.2). Then, the expression (3) would tell that net external works (***friction work is not any more external***) goes to change the mechanical and thermal energies of the system.

Example: A block with mass **m=10kG** moving with speed $\boldsymbol{\upsilon = 5m/s}$ stops at distance "***d*** " on a horizontal plane that exerts a friction force $\boldsymbol{f_k = 5N}$ on it.



a) Find the *change of thermal energy* $\boldsymbol{\Delta E_{th}}$ of ***block - plan set*** and **b)** Find "***d*** "

If one sees the words *temperature or thermal,* one may ***exclude the work by friction from the external work*** *and refer to the* ***principle energy in form (3).***

By excluding the friction from external forces, in this example one get $\boldsymbol{W_{ext} = 0}$ *and the equation (3) gives*

$\Delta E_{mech} + \Delta E_{th} = W_{ext} = 0$ or $\Delta(U_G+K) + \Delta E_{th} = 0$ or $\Delta U_G + \Delta K + \Delta E_{th} = 0$ and $\Delta K + \Delta E_{th} = 0$

because $\Delta U_G = 0$ *(same height) So,* $(0 - 10*25/2) + \Delta E_{th} = 0$ *and* ***a)*** $\Delta E_{th} = E_{th2} - E_{th1} = 125\ J$

b) As, $\Delta E_{th} = |W_f| = f_k*d$ *it comes out that* $125J = 5N*d$ *and* $\boldsymbol{d = 25m}$

Note: The models that take into account the changes in internal energy of objects are used mainly in the frame of thermodynamics. In this course, we refer *mainly* to a system where ***friction is an external force*** ($\boldsymbol{W_f}$ is an external work) and use the principle of mechanic energy conservation for a material point model

$$\mathbf{W_{ext\_net} = \Delta E_{mech} = \Delta K + \Delta U} \qquad (5)$$

One will calculate the total amount of thermal energy produced from the work by friction as $\boldsymbol{\Delta E_{th} = -W_f}$.

Important: The experiments show that **K** and **U** can ***transform completely*** into each other or into $\mathbf{E_{th}}$ but $\mathbf{E_{th}}$ cannot transform ***completely*** into ***K*** or ***U***. ***A disorganized motion cannot be converted naturally (by itself) into an oriented motion.*** *Ex: A hot block at rest cannot start moving along one direction just because its temperature decreases*. That's why the *thermal energy is* ***not considered*** *as a pure mechanical energy.* Also, one measures the *thermal energy* (*or heat*) by a particular unit "calorie" (**1 cal = 4.186 J**)

2] OTHER TYPES OF INTERNAL ENERGY

- Let's consider an *exothermic* ***chemical reaction*** inside a sealed container. The molecules "***A"*** interact with molecules ***"B"*** at room ***temperature*** and produce molecules ***A-B*** . The chemical reaction releases heat which increases the ***temperature*** ($\Delta E_{th} > 0$) in container**.** If the ***thermal energy*** of particles in sample increases too much**,** it may be produced an *explosion(and container can break)* **.** As the system of molecules (A and B) is *isolated* ($W_{ext} = 0$), the principle of energy conservation (3) would tell that $\boldsymbol{\Delta E_{mech} + \Delta E_{th} = 0}$ *but the experiment shows that* $\Delta E_{mech} > 0$ and $\Delta E_{th} > 0$**,** which means that is $\boldsymbol{\Delta E_{mech} + \Delta E_{th} > 0}$.

One can avoid this contradiction if one takes into account that there is a ***molecular energy*** *inside each of the* ***molecules*** in container. One can figure out that the total amount of this type of energy over all molecules in container "$\boldsymbol{E_{mol}}$ " remains constant as long as there is ***no chemical reaction***. But, it does change when a chemical reactions happen . So, the total energy of molecules in container is

$$E_{tot} = E_{mech} + E_{th} + E_{mol} \qquad (6)$$

Next, the principle of energy conservation for an isolated system would be written $\Delta E_{tot} = \mathbf{W_{ext} = 0}$

$\Delta E_{mech} + \Delta E_{th} + \Delta E_{mol} = 0$ and $\Delta E_{mech} + \Delta E_{th} = -\Delta E_{mol} > 0$ ***i.e.*** $\Delta E_{mol} = E_{mol-2} - E_{mol-1} < 0$

This means that, during an *exothermic* ***chemical reaction,*** the amount of energy ***lost*** by E_{mol} part of its *internal energy* goes to increase the *mechanical and thermal energy of the system* .

-Inside a battery, the *molecular energy* get transformed (***via a chemical reaction***) into ***electrical energy*** E_{elect} which is another type of *internal energy*. There is a set of other ***internal energies*** (E_{struct} *in a solid or liquid structure,* E_{at} *- atomic energy inside the atoms,* E_{nucl} *- nuclear energy inside the nuclei and* E_{rad} *- radiation energy*) which cannot transform ***completely*** and ***naturally*** into ***pure mechanic energy*** (**K** or **U**). So, they are all ***non-mechanical*** forms of energy. If one group all them into a single term E_{int} (*internal energy*), one gets

$$E_{int} = E_{electr} + E_{struct} + E_{mol} + E_{at} + E_{nucl} + E_{rad} \quad (7)$$

and the ***total energy*** of an object can be expressed as

$$E_{tot} = E_{mech} + E_{th} + E_{int} \quad (8)$$

In mechanics, one prefers to distinguish the term E_{th} ***from other terms of*** E_{int} ***.***

3] GENERAL PRINCIPLE OF ENERGY CONSERVATION

The results of ***multiple experiments*** confirm the following:

- If one includes ***inside a system all the objects that may interact to each other***, one creates an ***isolated system***. The ***total energy*** of an ***isolated system*** ***remains constant*** **in time i.e.**

$$\Delta E_{tot} = \Delta E_{mec} + \Delta E_{th} + \Delta E_{int} = 0 \quad (9)$$

Note: *This does not exclude motion and energetic exchanges inside the system; but if they happen, the amount of energy transformed from one form to another is such that the* ***total energy remains constant****.*

- *If the system is* ***not isolated*** *the* ***amount of energy*** *that it exchanges with* ***adjacent space regions*** $E_{exchange}$*,*

is equal to the change of its total energy

$$\Delta E_{tot} = E_{tot-2} - E_{tot-1} = E_{exchange} \quad (10)$$

If the system ***exchanges only work*** *with* ***adjacent space regions***, then

$$E_{exchange} = W_{ext} \quad (11)$$

and

$$W_{ext} = \Delta E_{mech} + \Delta E_{th} + \Delta E_{int} \quad (12)$$

Remember:

****The total energy of system increases if* $W_{ext} > 0$ *and decreases if* $W_{ext} < 0$.

*** The work by friction is not included into* W_{ext} *at expressions* ***(3, 11, 12).***

The ***principle of total energy conservation *(12)* transforms into form $W_{ext} = \Delta E_{mech}$ when $\Delta E_{int} = 0$.