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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 material objects are constituted by *atoms* (*or molecules*) which "***interact** between them and **move** inside the object"* and this means some "***energy inside the object*** ". 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***. Also, no matter what is the ***physical state***(*solid, liquid or gas*) of an object, its *atoms* (*or molecules*) are in a ***continuous random motion***. This type of motion is characterized by an ***average speed*** of moving particles 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*. ***Thermal energy*** "$\mathbf{E_{th}}$" is the amount of energy related to the *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> $\boldsymbol{E_{th}}$ of the two bodies (*hands get warm*). Precise measurements show that the *increase* of *thermal energy **of** the two bodies* is equal to the ***magnitude*** of work done by friction.

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

As 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 in Fig. 1 principle and get

$$\boldsymbol{W_{ext\_net}} = \boldsymbol{W_{ext}} + \boldsymbol{W_f} = \Delta \boldsymbol{E_{mech}} \quad (2)$$

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

$$\boldsymbol{W_{ext}} = \Delta \boldsymbol{E_{mech}} + \Delta \boldsymbol{E_{th}} \quad (3)$$

-Note that $\boldsymbol{W_{ext}}$ 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*** $\boldsymbol{\Delta E_{th\text{-}sys}}$ ***and*** *that of the* **external objects** $\boldsymbol{\Delta E_{th\text{-}obj}}$ ***in contact*** *with system parts* (fig.1).

$$\Delta \boldsymbol{E_{th}} = \Delta \boldsymbol{E_{th\_sys}} + \Delta \boldsymbol{E_{th\_obj}} \quad (4)$$

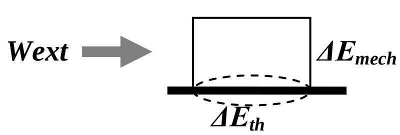


Fig.1

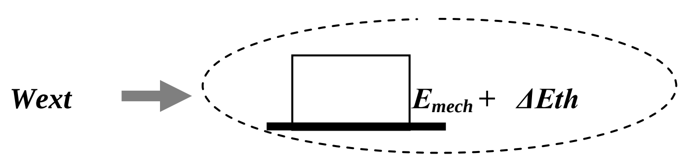
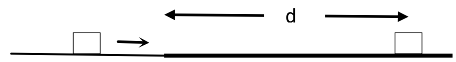


Fig.2

One may include into system the "*adjacent objects affected by friction"* and consider the friction as an ***internal*** <u>***but***</u> ***non-conservative*** force of system (fig.2). Then, the expression (3) would tell that net external work (***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** that starts sliding at speed $\boldsymbol{v = 5m/s}$ on a horizontal plane stops at a distance "***d*** " due to friction force $\boldsymbol{f_k = 5N}$ applied on it by plan.



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 relation (3) gives*

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

because $\Delta U_G = 0$ *(same height) So,* $(0 - 10*5^2/2) + \Delta E_{th} = 0$ *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***

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

If requested, one calculates the *total amount of thermal energy* produced from the work by friction as $\boldsymbol{\Delta E_{th} = -W_f}$.

<u>**Important**</u>**:** The experiments show that **K** and **U** can ***transform <u>completely</u>*** into each other ***or*** into $\mathbf{E_{th}}$ but $\mathbf{E_{th}}$ cannot transform <u>***completely***</u> 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* <u>***not considered***</u> *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 <u>*exothermic*</u> ***chemical reaction*** inside a sealed container. The molecules "***A***" interact with molecules "***B***" at room ***temperature*** and produce molecules ***A-B***. Simultaneously, 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 pieces of sample get out container at high speed (i.e. they get kinetic and gravitational energy changes).* As the sample of molecules (A, B and A-B) is an <u>*isolated*</u> system ($\boldsymbol{W_{ext} = 0}$), the principle of energy conservation (3) would tell that $\mathbf{\Delta E_{mech}} + \boldsymbol{\Delta E_{th} = 0}$. But *the experiment shows that* $\mathbf{\Delta E_{mech}} > 0$ and $\boldsymbol{\Delta E_{th} > 0}$, which means that $\mathbf{\Delta E_{mech}} + \boldsymbol{\Delta E_{th} > 0}$. One can avoid this contradiction by taking into account that there is a ***molecular energy*** *inside each of the* ***molecules*** and label the total amount of this type of energy over all molecules in container as "$\boldsymbol{E_{mol}}$" . This energy remains ***constant*** as long as there is ***no chemical reaction, but*** it changes when a chemical reaction happens. So, the total energy of all 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 $\Delta E_{tot} = W_{ext} = 0$

$\Delta E_{mech} + \Delta E_{th} + \Delta E_{mol} = 0$ 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 <u>*exothermic*</u> ***chemical reaction,*** the amount of energy ***lost*** ($\Delta E_{mol} < 0$) by the *internal molecular energy of the system* goes to increase its *mechanical and thermal energy*.

-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 exist 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 <u>***completely***</u> and <u>***naturally***</u> into <u>***pure mechanic energy***</u> (**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*) without including E_{th}, 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 $E_{tot} = E_{mech} + E_{th} + E_{int}$ (8)

Note: 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 <u>***isolated system***</u>. The ***total energy*** of an <u>***isolated system***</u> ***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* ***i****nside the system; but if they happen, the amount of energy transformed from one form to another form 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 $\Delta E_{tot} = E_{tot-2} - E_{tot-1} = E_{exchange}$ (10)

If the system ***exchanges only work*** *with* ***adjacent space regions***, then $E_{exchange} = W_{ext}$ (11)

and $W_{ext} = \Delta E_{mech} + \Delta E_{th} + \Delta E_{int}$ (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 $\Delta E_{int} = 0$.