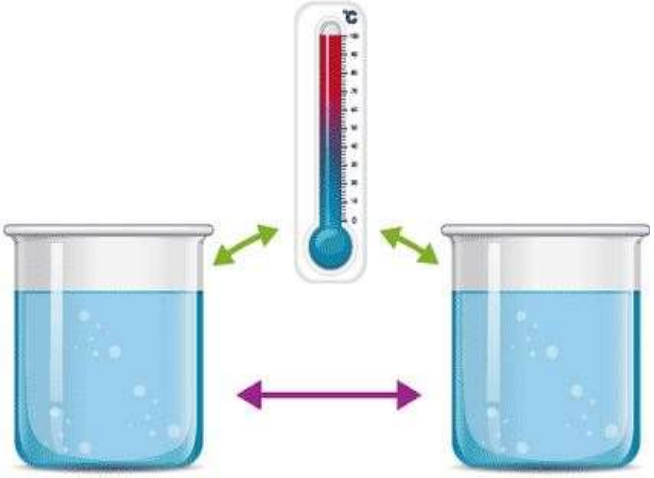

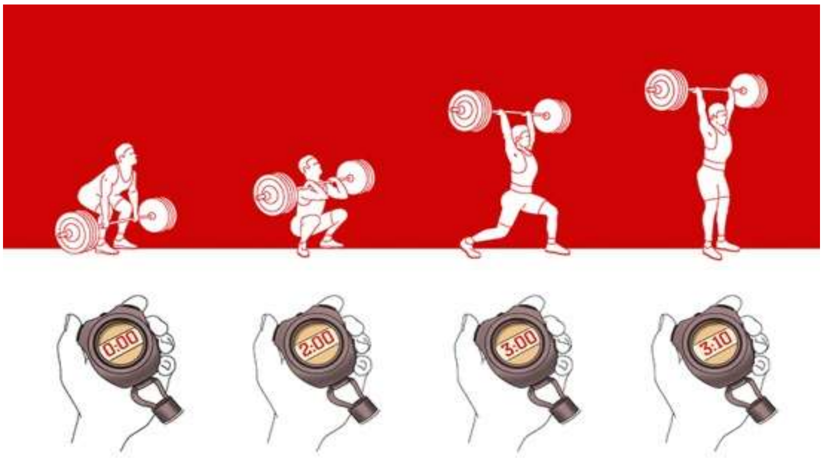

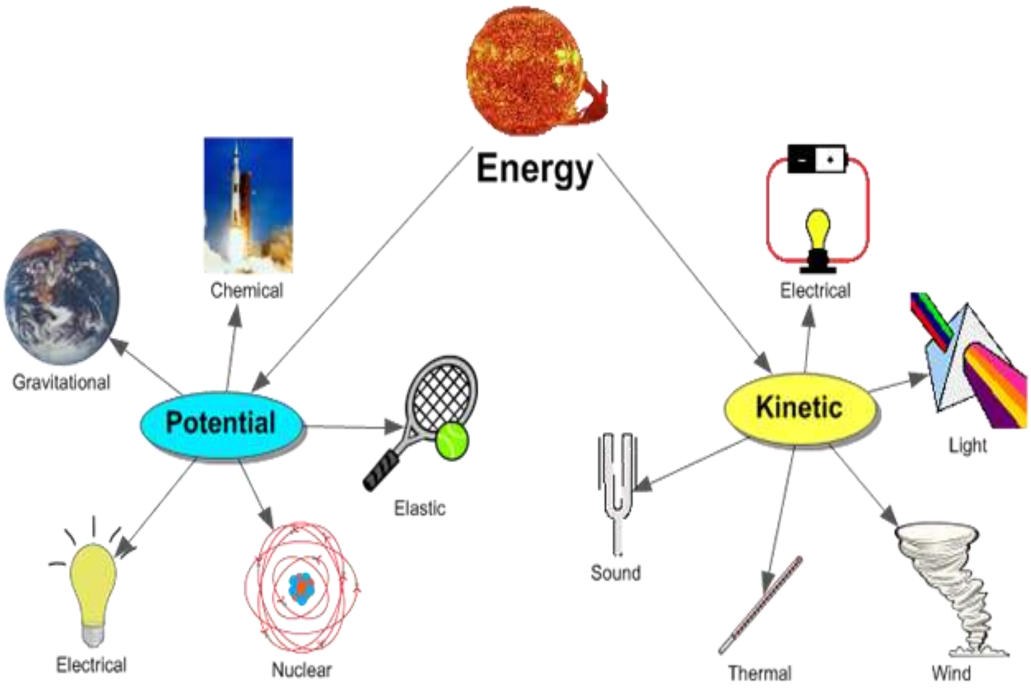

Work, Energy, and Power of the Body

First Lecture (1)

First semester / First year

By

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Work, Energy, and Power

Work of the Body:

Work: is the result of applying a force (a push or pull) to an object, which causes a displacement of the object. For work to be done, a force must be exerted, and there must be motion or displacement in the direction of the force, as shown in figure 1. Work has only magnitude and no direction. Hence, work is a scalar quantity. The SI unit of work is the Joule (J), which is equal to (N.m).

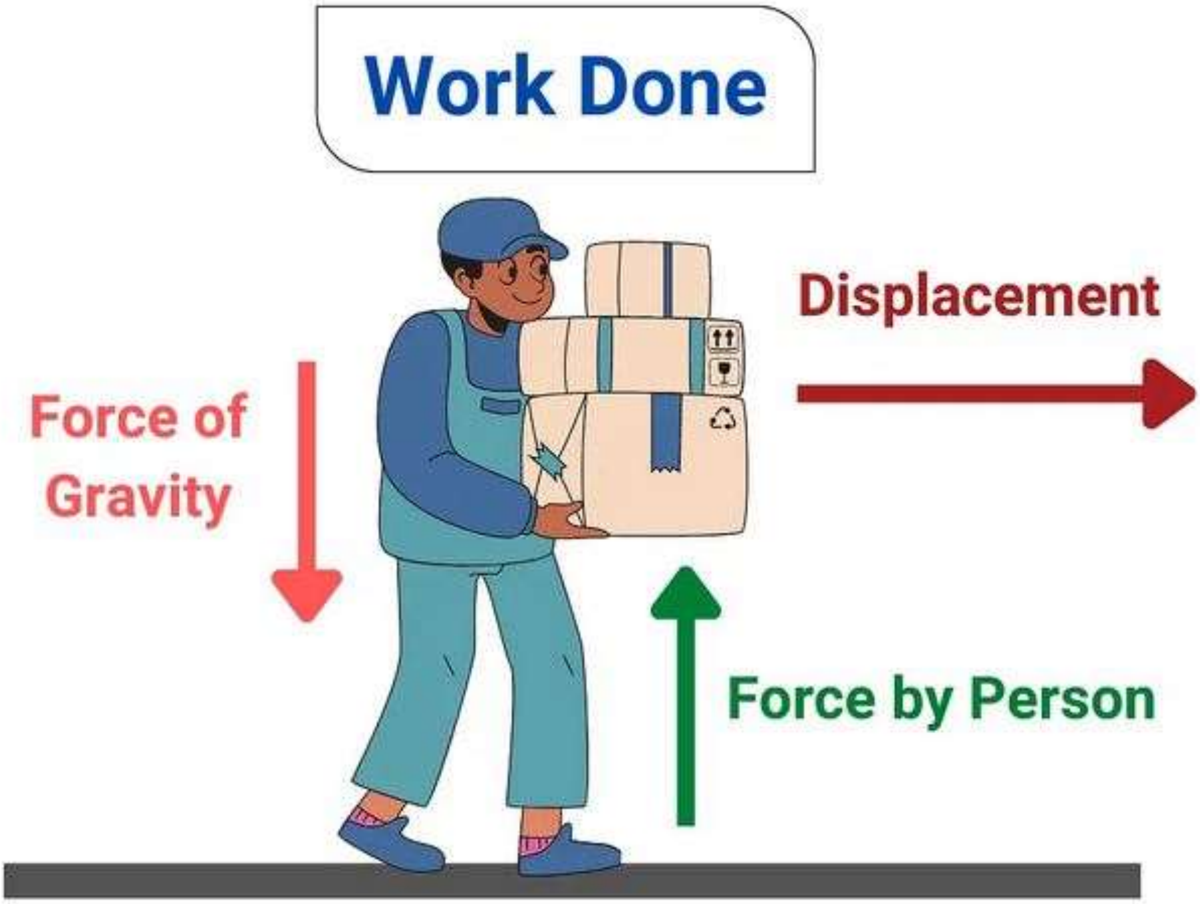

Figure (1): Shows the work done by a human body.

The work is defined as the product of the component of the force in the direction of the displacement and the magnitude of this displacement; it's introduced in the following equation:

$$W = F.d = F\, d \cos\Theta \quad \ldots\ldots (1)$$

Where:

W: is the work done

F: is the force

d: is the displacement

Θ: is the angle between the direction of motion and the applied force.

NOW, What are the Cases where the Work done can be ZERO?

To summarize, we can say that no work is done if:

1. ***The force and displacement are mutually perpendicular to each other.*** You can see that for values of ϴ for which the cosine of the angle is 0, no net work is done (Cos 90 = 0).
2. ***The displacement is zero***; we understand from the work equation that if there is no displacement, there is no work done, irrespective of how large the force is.
3. ***The force is zero.***

Example of Work:

1. An object is horizontally dragged across the surface by a 100 N force acting parallel to the surface. Find out the amount of work done by the force in moving the object over a distance of 8 m.

Solution:

The given values in the question are: F = 100 N, d = 8 m.

Since F and d are in the ***same direction***, θ = 0 [θ is the angle of the force to the direction of movement], therefore:

W = Fd Cos θ

W = 100 x 8 x Cos 0, [Since Cos 0 = 1]

W = 800 J.

So, the amount of work done is: W = 800 J.

2. A dog pulling a 20 kg child-sled combination across a horizontal snowfield accelerates from rest to a velocity of 5 m/s over the course of 5 seconds ($a = 1\ m/s^2$). How much work does the dog do on the child-sled combination? Assume friction is negligible.

Solution:

The given values in the question are: m = 20 kg, v = 5 m/s, t = 5 s, and $a = 1\ m/s^2$.

From Newton's Second Law:

F = ma

F = 20 x 1

The force is: F = 20 N

Since the displacement is the average velocity multiplied by time t:

$$d = \frac{V - V_O}{2} \text{ x } t = \frac{5-0}{2} \text{ x } 5 = \frac{5}{2} \text{ x } 5$$

The displacement is: d = 12.5 m

Therefore, the Work done is:

W = Fd Cos θ

W = 20 x 12.5 x Cos 0, [Since Cos 0 = 1], W = 250J

W = 250 J.

So, the amount of work done is: W = 250 J.

Energy of the Body:

Energy: is the ability of the body to do a work. The more work done, the more energy is used to do this work. The unit for energy is the joule (J).

Types of Energy:

Although there are many forms of energy (See figure 2), they are broadly categorized into:

- **Kinetic Energy:** is the energy associated with the object's motion. To better understand, an example of kinetic energy is the energy of the random bouncing of atoms or molecules. This is known as ***"thermal energy".***
- **Potential Energy:** is the energy stored in an object or system of objects. Potential energy can transform into a more obvious form of kinetic energy.

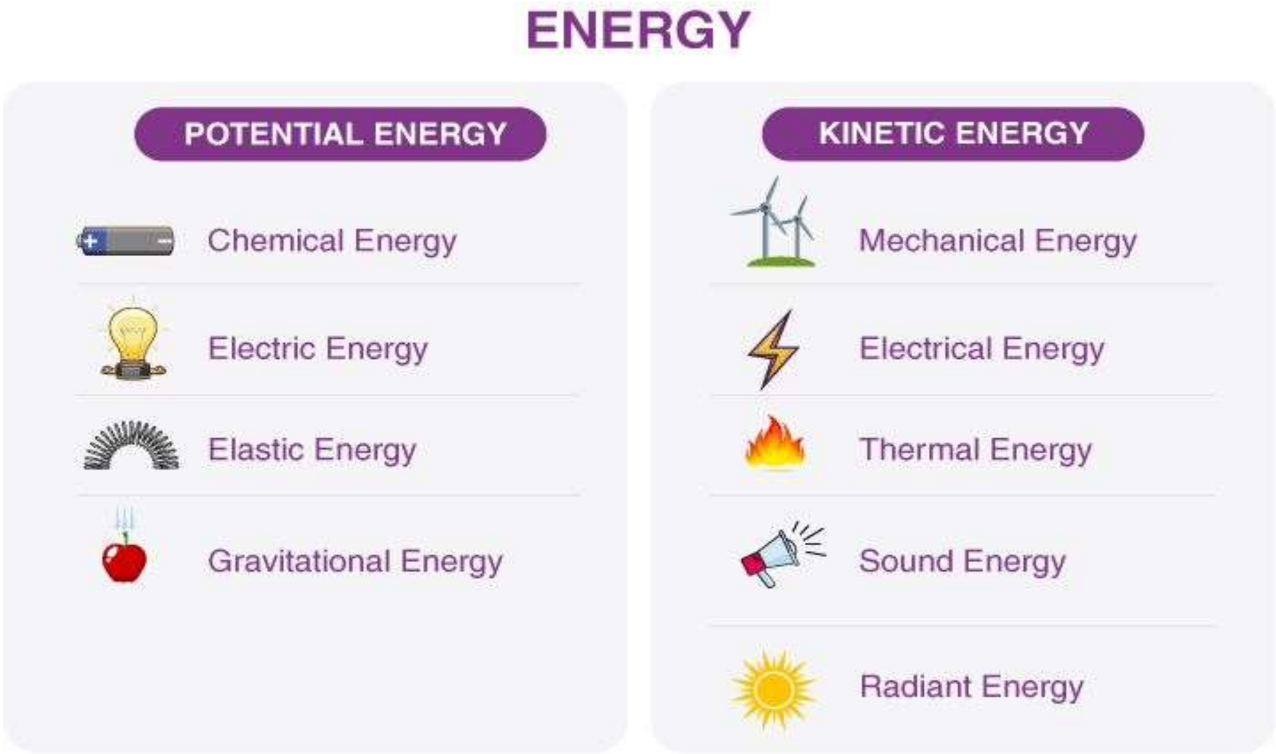

Figure (2): Shows forms of Energy.

Energy also comes in a variety of forms, which we can classify as:

- Gravitational Energy
- Chemical Energy
- Electrical Energy
- Mechanical Energy
- Nuclear Energy
- Elastic Energy
- Solar Energy
- Sound Energy
- Light Energy, and so on.

The basic two general kinds of energy that all objects in the universe, including our bodies, may have some of the organs in the body have kinetic energies, such as the bones and muscles movements, heart beatings, blood circulating, and lungs and stomach movements.

NOW, What is the body's basic source of Energy and what is it used for?

The body's basic energy (fuel) source is ***food***; the food must be chemically changed by body molecules that can combine with oxygen in the body. Extra food energy will be stored mainly as ***fat***. The energy supplied by food to our bodies is measured by the unit's joule, or unit calorie. Figure 3 shows the methods of energy transfer. 1 cal = 4.184J, or 1 K cal = 4184J.

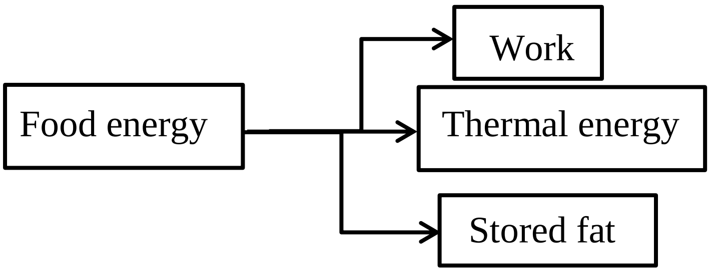

Figure (3): Shows the methods of energy transfer.

The body uses the food energy to:

1. Operate its various organs.
2. Maintain a constant body temperature.
3. Do external work, e.g., lifting.

In human body, because of the energy stored in the cells, the cells are capable of doing work. The heat released in the body cannot be changed to work because our body is not a heat engine, but the heat is used to maintain the temperature of the body, and the rest is dissipated outside of the body.

*Question: Does the human's body use Energy when it is not doing work?

There are continuous energy changes in the body, both when it is doing work and when it is not. Under resting conditions, the body's energy is being used as follows:

- 27% by the liver and spleen.
- 25% by the skeletal muscles.
- 19% by the brain.
- 10% by the kidney.

NOW, The human body can detect the Energy; how?

There are two ways the human body can detect energy:

Directly:

1. Our ears can detect sound energy
2. Eyes respond to visible light
3. Special nerves are sensitive to temperature, which indicates heat energy, and other nerves respond to electric energy as nerve signals.

Indirectly:

We can sense chemical, electrical, magnetic, gravitational, and nuclear energies; some kinds of energy we can sense by devices; and kinds of radiation like particles and rays such as α, β particles and X-Rays, figure 4 Show the devices that can detect energy, such as the Geiger Muller Counter.

Figure (4): Show the devices that can detect energy.

Energy Changes in the Body:

All activities of the body, including thinking, involve energy changes. The conversion of energy into work occurs continuously in the body. The first law of thermodynamics basically relates to the changes in energy states due to work and heat transfer.

The First Law of Thermodynamics:

Energy is a conserved quantity; according to the laws of conservation of energy, ***"energy can neither be created nor destroyed but can only be converted from one form to another".*** Thermodynamics is the branch of science that deals with heat and temperature and the inter-conversion of heat and other forms of energy. In thermodynamics, a system that is delimited from the surroundings by real or hypothetical boundaries is known as ***"a thermodynamic system".*** The system contains energy, which can be transferred to the surroundings. The surroundings contain everything other than the system. The system and the surroundings together make up the universe. Figure 5 shows the difference between a system, system boundary, and a surrounding.

The Universe = The System + The Surroundings

Thermodynamic Systems are Classified as:

1. Open Systems
2. Closed Systems
3. Isolated Systems

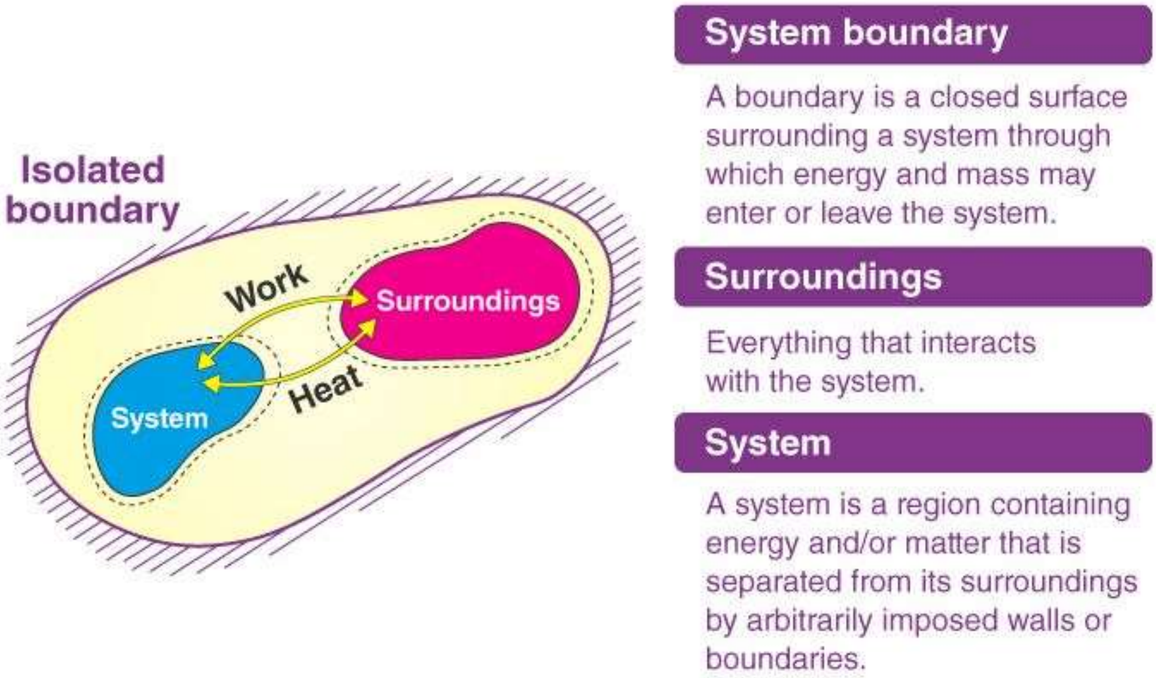

Figure (5): Shows the difference between a System, System Boundary, and a Surrounding.

The first law of thermodynamics is a formulation of the law of conservation of energy in the context of thermodynamic processes. The energy of the universe remains the same. Though it may be exchanged between the system and the surroundings, it can't be created or destroyed; however, it can be transferred from one location to another and converted to and from other forms of energy. The law basically relates to the changes in energy states due to work and heat transfer. It redefines the conservation of energy concept.

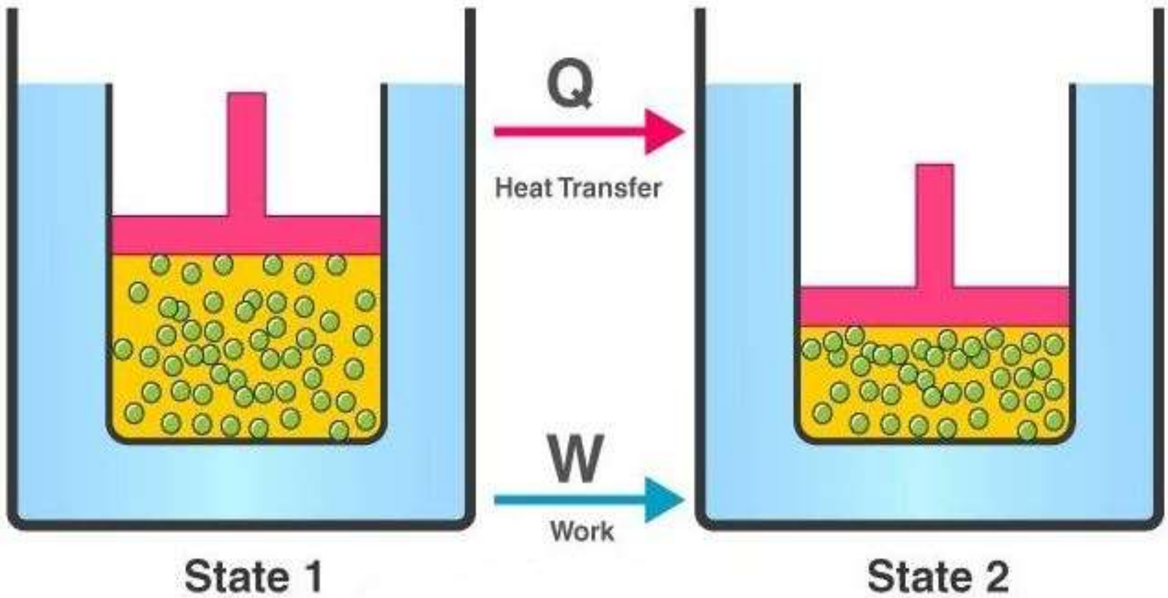

Figure (6): Shows the first law of thermodynamics.

Figure 6 shows the first law of thermodynamics. A thermodynamic system in an equilibrium state possesses a state variable known as ***"internal energy".*** Between the two systems, the change in internal energy is equal to the difference between the heat transfer into the system and the work done by the system.

We can write the first law of thermodynamics as:

$$\Delta U = Q - W \quad \text{….. (2)}$$

Where:

ΔU: is the change in stored energy (Internal Energy)
Q: is the heat lost or gained
W: is the work done by the body.

So, the first Law of Thermodynamics is a statement about the conservation of energy, and it categorizes the method of energy transfer into two basic forms (See figure 7):

1. **Work (W)**
2. **Heat (Q)**

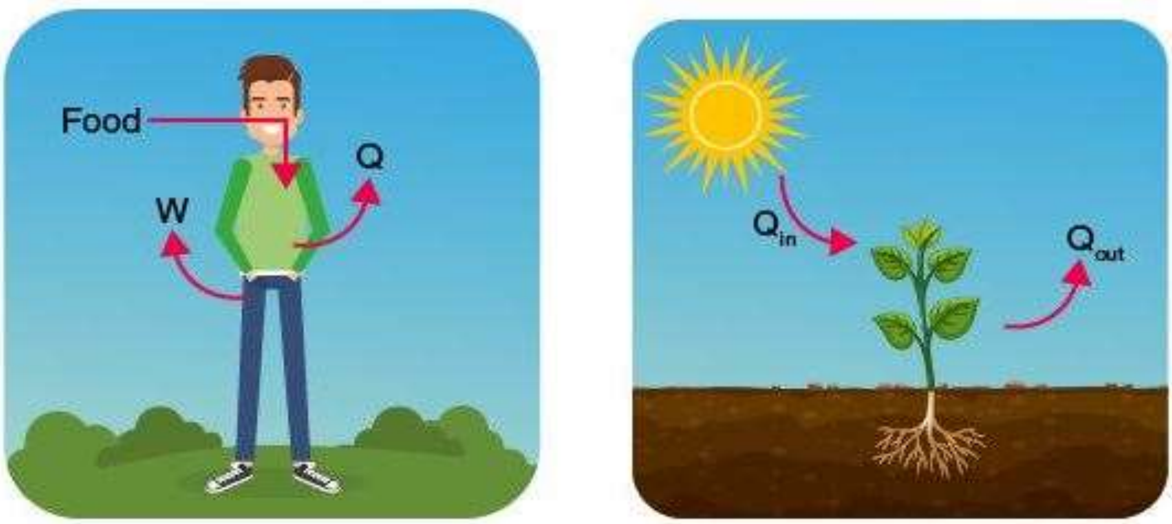

Figure (7): Shows the relationship between energy, heat, and work done on and by the system.

***NOTE*:**

We need to be careful about the following signs:

- When the Heat is added to the system, Q_{in} is positive, and the W done ***by*** the system is positive.
- When the Heat is leaving the system, Q_{out} is negative, and the W done ***on*** the system is negative.

Example of the Energy Changes:

1. **Calculate the change in the system's internal energy if 3000 J of heat is added to a system and a work of 2500 J is done by the system.**

Solution:

Because the heat was added to the system, Q is positive, and W is positive because the work was done by the system.

Hence, the change in internal energy is given as:

$\Delta U = \Delta Q - \Delta W$

$\Delta U = 3000 - 2500$

$\Delta U = 500$ J.

<u>So, the internal energy of the system is: $\Delta U = 500$ J.</u>

2. What is the change in the internal energy of the system if 2000 J of heat leaves the system and 3000 J of work is done on the system?

<u>Solution</u>:

Because the heat was <u>leaving</u> the system, Q is <u>negative</u>, and W is <u>negative</u> because the work was done <u>on</u> the system.

$\Delta U = \Delta Q - \Delta W$

Substituting the values in the following equation, we get:

$\Delta U = -2000-(-3000)$

$\Delta U = -2000+3000$

$\Delta U = 1000$ J.

<u>So, the internal energy of the system is: $\Delta U = 1000$ J.</u>

Power of the Body:

<u>Power:</u> is defined as energy or work per time; the unit of power is the watt, equal to one joule per second (Watt = J/s), as shown in figure 8. The power can be calculated using the following equation:

$$P = \frac{W}{\Delta t} \quad \text{.....} \ (3)$$

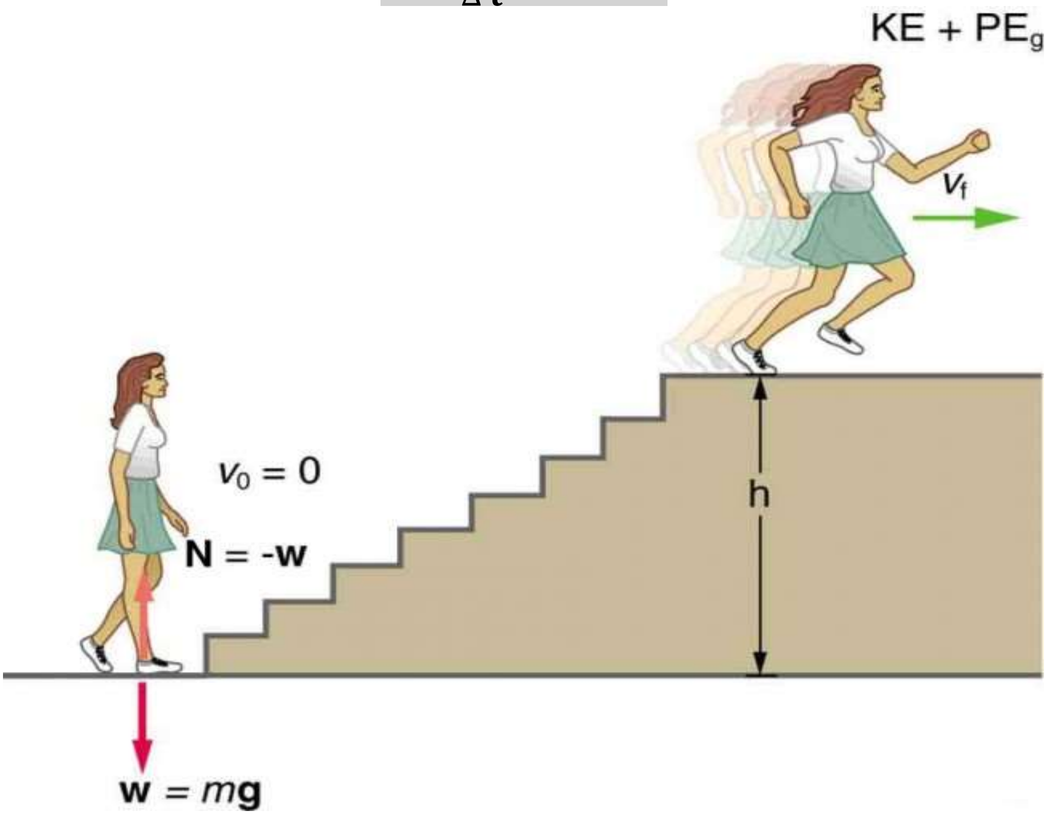

Figure (8): Shows the power of a human boy.

Figure 8 show that when this woman runs upstairs, starting from rest, ***she converts the chemical energy originally from food into kinetic energy and gravitational potential energy.*** Her power output depends on how fast she does this. Note that you do the same amount of work when you climb the stairs of a building in 2 minutes or 6 minutes, but your power output is not the same because it depends on the time interval spent doing work.

Example of the Power of the Body:

Calculate the power of the cell for breaking the glucose molecule in one second, where the energy of ATP, which converted to work, is 262 Kcal.

Solution:

The given is: W= 262 Kcal, t = 1 sec.

$$\mathbf{P} = \frac{\mathbf{W}}{\Delta \boldsymbol{t}}$$

$$P = \frac{262 \text{ Kcal}}{1\ Sec}$$

P = 262 Kcal/sec

Since 1 Kcal = 4184 J

P = 262 x 4184 J/sec

P = 1.0 x 10^6 J/sec

P = 1.0 MW.

So, the power is: P = 1.0 MW.