Homework 12

Energy

1. **Kinetic energy**

Energy is a scalar physical quantity which expresses the ability of an object to do work. It means that an object which possesses some energy can interact with other objects and cause changes in their positions and velocities. An object with higher energy can do more work. There are many forms of energy – kinetic, potential, thermal, chemical, nuclear etc.

Energy conserves. It means that energy cannot be created or destroyed – it can only be transferred from one form into another. For example, a power plant does not create electrical energy. A power plant converts kinetic energy of water flow or chemical energy of fuel into electrical energy. When a battery of, say, a flashlight is depleted, it does not mean that the energy previously stored in the battery just disappeared. The energy was just converted into thermal energy and energy of light.

We start with ***kinetic energy***. The ***kinetic energy*** of an object is the extra energy which it possesses due to its motion. Any moving object possesses kinetic energy. If two objects have same mass, the one with higher speed has higher energy. (I used the word “speed” instead of “velocity” because only the magnitude of velocity is important for the kinetic energy). If the speeds of two moving objects are equal, the object with higher mass will have higher kinetic energy. Kinetic energy can be calculated using the formula:

$$E_{kinetic} = \frac{m \cdot V^2}{2},$$

where ***m*** is mass, ***V*** is speed. The International System unit to measure energy is Joule (J).

$$1J = 1\frac{kg \cdot m^2}{s^2}$$

It is named after James Prescott Joule (1818-1889) – English physicist and brewer. Many scientists contributed to discovery and understanding of the energy conservation law. Among these were James Joule, Hermann Helmholtz and Julius Meyer.

James Prescott Joule

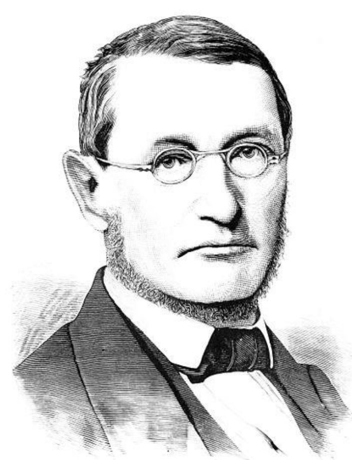
(1818-1889)

Hermann Ludwig Ferdinand

von Helmholtz

(1821-1894)

Julius Robert von Meyer (1814 – 1878), German physician and physicist whose name is associated with the first formulation of the energy conservation law. Famous Japanese physicist, Ryogo Kubo describes the discovery of Julius Meyer as follows:



Julius Rober von Mayer

(1814-1878)

Julius Robert Mayer (1814–1878) was really a genius who was born in this world only with the errand to make this great declaration. Hermann Ludwig Ferdinand von Helmholtz (1821–1894) gave this law the name "Erhaltung der Kraft" or "the conservation of energy". Like Mayer, he started his career as a medical doctor but lived a glorious life as the greatest physiologist and physicist of the day. James Prescott Joule (1818–1889) worked over forty years to establish the experimental verification of the equivalence of work and heat.

Among the three, Mayer was the first who arrived at this law and the last whose work was recognized. His life was most dramatic. A lightening stroke of genius overtook him, a German doctor of the age of twenty six, one day on the sea near Java when he noticed that venous blood of a patient under surgical operation appeared an unusually fresh red. He considered that this might be connected with Lavoisier's theory of oxidation in animals, which process becomes slower in tropical zones because the rate of heat loss by animals will be slower there. A great generalization of this observation lead him to the idea of the equivalence of heat and mechanical work. For three years after his voyage, while he was working as a medical doctor at home, he devoted himself to complete the first work on the conservation of energy "Bemerkungen über die Kräfte der unbelebten Natur" which was sent to the Poggendorf Annalen and was never published by it. In 1842 Liebig published this paper in his journal (Annalen der Chemie und Pharmacie) but it was ignored for many years.

Mayer wrote four papers before 1851. During these years of unusual activity he cared for nothing other than his theory. In 1852 he became mentally deranged and was hospitalized. He recovered after two years but never returned to science. ”

Ryogo Kubo, "Thermodymamics"

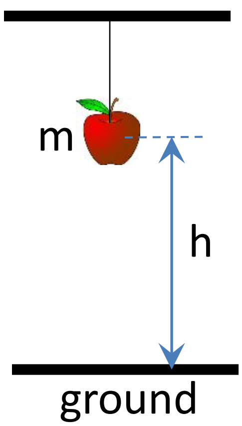
It looks like despite the kinetic energy having a simple expression it is tricky to calculate it. Even if an object is on Earth and is at rest with respect to the ground, it is moving with respect to the Sun. Do we have to take this motion into account? Generally, yes - especially taking into account that this is accelerated motion. But for many processes the effect of the Earth motion is small and can be neglected. While absolute kinetic energy depends on the reference frame and does not have much sense, the *change in kinetic energy* in a certain process is much more meaningful.

2. Potential energy

We can think about potential energy as of the energy "stored" in the system. Unlike kinetic energy which depends on the object's *velocity*, potential energy depends on the *position* of the physical body with respect to other objects with which the body interacts. Expression for potential energy depends on the type of interaction between the objects. Here we discuss how to calculate the potential energy in case of gravity force.

Any object with mass is attracted by Earth. The higher is the position of the object over the ground, the stronger it will hit the ground when it falls. It is natural to assume that potential energy depends on the distance between the object and the ground. When a stone starts falling it accelerates toward the Earth. The kinetic energy of the stone increases. At first glance it looks like the energy is created as the stone goes down. But this statement is not correct. The total energy of the stone remains constant as the stone is falling down, in full agreement with the energy conservation law. The total energy of the stone is the sum of potential and kinetic energies. In the highest point kinetic energy is zero and potential energy is maximal. At the lowest point, just before the stone hits the ground, potential energy is minimal and kinetic energy is maximal. Potential energy corresponding to the gravity force can be calculated as

$$E_{potential} = m \cdot g \cdot h$$



Here *m* is the mass of the object; *g* is acceleration due to gravity, *h* is the distance between the object and, say, the ground. There are two important points:

1. As with the kinetic energy absolute value of potential energy does not make much sense. We can count h from any level when solving a problem. What does make sense it is *change* in the potential energy in a certain process. This change will not depend on the “zero potential energy level” which you can choose arbitrary.
2. The formula above is valid only if the object is close enough to the Earth – the distance between the object and the Earth should be much less than the radius of Earth.

Problems:

1. Calculate kinetic energy of a falling stone with a mass of 10kg after 3 second of falling.
2. Imagine that both the mass and the speed of a moving object increased 2 times. How did its kinetic energy change?
3. It is possible to use the energy of tidal waves to produce electricity. For a first glance this is an eternal (well, almost eternal – as long as the Earth and Moon exist) energy source. Is it true? Explain your answer.

4. A 1 kg stone is falling down from a height of 10m. Calculate kinetic and potential energies of the stone in the upper, middle and lower points. Please calculate the kinetic energy through the calculation of the stone's velocity and show that the total energy of the stone remains constant as it goes down.
5. A 10g bullet is sent up at a speed of 300m/s. How high will it go? Solve this problem by two ways.
6. A 50g ball is falling down. As the ball passes a certain distance its potential energy changes for 2J. Calculate this distance. Does this distance depend on the initial velocity of the ball?