Grade 12 Physics

SPH4U

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Contents

Chapter 3

Unit 2: Energy and Momentum

3.1 Work and Kinetic Energy

3.1.1 Kinetic Energy

Definition 3.1.1. *Kinetic energy is the energy of motion. There are two types of kinetic energy*

Type 1: Traslational Kinetic Energy

The kinetic energy that an object has because it is *moving from on location to another*. In can be describe by this formula:

$$E_k = \frac{1}{2}mv^2 \tag{3.1}$$

E_k is the translational kinetic energy of the object (in J or kgm^2/s^2)
m is the mass in kg
v is the speed in m/s

Because all motion is relative, an object's speed (and therefore E_k) *depends on the choose Frame of Reference*

Notes:

Do not solve the conservation of energy problem involving a change of Frame of Reference. Start from your perspective

E_k is a scalar, not a vector

Type 2: Rotational Kinetic Energy

Not testable, don't give a shit about this qusetion.

3.1.2 Mechancial Work

Definition 3.1.2. *Mechanical work: Transfer of energy into E_k or the transfer of kinetic energy into another type of energy*

Definition 3.1.3. *Potential energy: Energy which is stored in a system of objects due to forces acting in between thos objects*

The formula to descirbe the work is:

$$W = F_{A/B} * \Delta\vec{d}_B * cos\theta \tag{3.2}$$

$W_{A/B}$ is the work that $F_{A/B}$ does on the object B. This is also the amount of E_k that object A transfers into object B when A exerts a force on B(in J)
$F_{A/B}$ is the magnitude of force that A exerts on B(in J)
θ is the angle between $F_{A/B}$ and B's displacement

Remainder: Only forces on the direction of displacement is responsible for the work

3.2 Gravational Potential Energy

3.2.1 Some boring definitions

Definition 3.2.1. *(Gravational Potential Energy): The energy storedf in a system of objects due to the force of gravity acting between those objects. In other words, the energy is stored collectively* ***among all*** *the objects in the system*

Whne the force of gravity acting on the two objects causes this stored GPE to be converted into kinetic energy, the kinetic energy is not **shared evenlly** between these two objects. In the class Example, the earth effectively gets **zero** and the care effectively gets **all of them**. Due to this reason, when we have two objects with a very large difference in mass, we can always assume that the GPE is **stored only in the smaller object**

3.2.2 Formulas for GPE

Formula 1

$$\Delta E_g = mg\Delta h \tag{3.3}$$

ΔE_g is the change in Potential gravational energy(in J)
m is the mass of the object (in kg)
Δh is the change in height (in m)
g is the acceleration due to gravity (in m/s^2)

Fromula 2

$$E_g = mg\Delta h \tag{3.4}$$

$E - g$ is related to the GPE of the object

Remark. For all questions related to the **Gravational Potential Energy**, you must set your reference height in the diagram. Or, Mr McCumber will forget to add 0.5 for your test!

3.3 The law of the Conservation of Energy

3.3.1 Boring Definitions

Definition 3.3.1. *(Law of the Conservation of Energy): Energy will neither created or destroy, only change from one form to another*

Remark. The law of the conservation of energy only works in a **closed isiolated** system. In reality, the only true **closed and isolated** system is the Universe

Mechancial Energy

Definition 3.3.2. *(Mechancial Energy): is the sum of the* ***kinetic energy*** *and g****gravational potential energy****.*

Mathematically:

$$E_m = E_g + E_k \tag{3.5}$$

3.3.2 Question solving techniques

When you solve a question about conversation of energy, always write this:

$$E_{m1} = E_{m2} \tag{3.6}$$
$$E_{k2} + E_{g2} = E_{k1} + E_{g1} + W_{ap} + W_f \tag{3.7}$$

Then, cross out terms which equal to **zero**

Remark. Remember to write this, or teacher will forget to add your marks!

3.4 String & Elastic Potential Energy

3.4.1 The Force of String

Definition 3.4.1. *(Spring Force): Can be wrote as F_{spring}. It is the force exerted by the spring on a object.*

According to the Hooke's Law, the **force exerted by a string** is proportional to the string's displacement. So we can express the relationships between them by some formulas:

Vector Version:

$$\vec{F_x} = -k\Delta\vec{x} \tag{3.8}$$

Scalar Version:

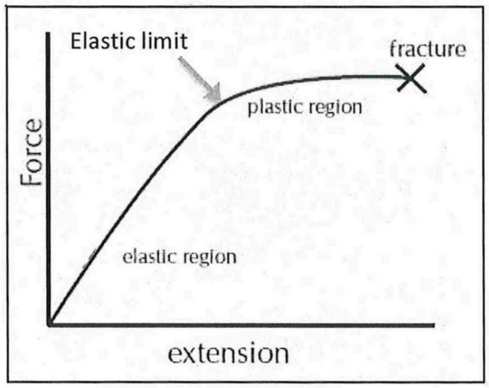
$$F_x = k\Delta x \tag{3.9}$$

F_x is the force exerted by the string on whatever stretches it.
k is the constant of string
x is the displacement of the spring from its unstratched

An essential feature of Hooke's law is that the direction of the spring force is **opposite** to the direction of displacement from equilibrium.

Remark. When you use the Scalar version, you must clearly understand the direction of the force in you heart.

Deeper explanation about Hooke's law



Definition 3.4.2. *(Elastic Region): Elastic objects obey Hooke's Law in this region. If the applied force removed, the object will naturally return back to its original shape*

Definition 3.4.3. *(Elastic Limit): The maximum amount of deformation an object can withstand, and still return to its original shape.*

Definition 3.4.4. *(Plastic region): The object no longer obeys Hooke's Law. The object's shape is now permanetly changed.*

Definition 3.4.5. *(Fracture): The maximum amount of shape change the object can take, prior to failing (breaking).*

3.4.2 Elastic Potential Energy

Definition 3.4.6. *(elastic potential energy): The potential energy due to the stretching or compressing of an elastic material*

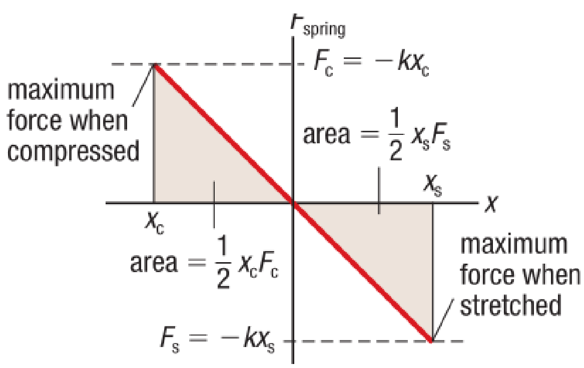


Figure 3.1: The work done by a variable force is equal to the area under the the force-displacement graph

Formula

$$W = \frac{1}{2} * \Delta x * F_{spring} \tag{3.10}$$

$$W = \frac{1}{2} * \Delta x * (k * \Delta x) \tag{3.11}$$

$$W = \frac{1}{2} * k * (\Delta x)^2 \tag{3.12}$$

The work done by the spring force is the negative of this amount, and is also the negative of the change in Potential Energy. That means that the work done stretching or compressing the spring is transformed into elastic potential energy.

$$E_e = \frac{1}{2}k(\Delta x)^2 \tag{3.13}$$

3.4.3 Ignore Gravational Potential Energy

We can ignore the Gravational Potential Energy in the vertial spring question if all of these conditions are met:

- The mass remains in contact with the spring
- We measure all changes in the length relative to the equilibrium position of the mass-spring system (ie. $x_{eq} = 0$)

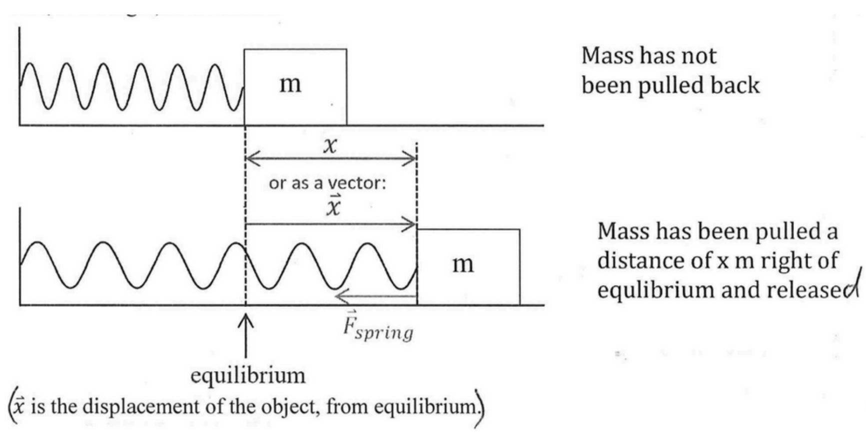
3.5 Simple Harmonic Motion

3.5.1 Definitions

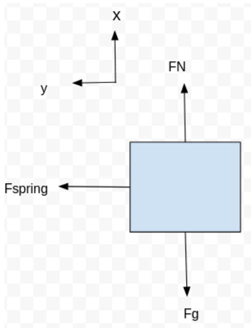
Simple Harmonic Motion

An object undergoes simple harmonic motion, if two conditions are met:

1. The net force acting on the object is **directly proportional** to the object's displacement away from equilibrium (The location where $\sum F = 0$)
2. The direction the net force acts on the object must be **opposite** the object's displacement from equilibrium.



Let see the FBD for m:



$$\sum \vec{F} = \vec{F_{spring}} \tag{3.14}$$
$$\sum \vec{F} = -k\vec{x} \tag{3.15}$$

Changing to proportionality:

$$\text{Net Force} \propto -\vec{x} \tag{3.14}$$

Expectations

If there was **friction** acting on the object, it would no longer undergo simple harmonic motion. We would call the motion of the object: **Damaged Harmonic Motion**

Some Real life examples:

- Car shock absorbers
- A guitar string
- A pendalam or a string
- Bungee jumping

3.5.2 How can we solve form the acceleration of SHM

Returning to our FBD of the mass and the net force statement from it:

$$\sum \vec{F} = m\vec{a} \tag{3.15}$$
$$\vec{F_s} = m\vec{a} \tag{3.16}$$
$$-kx = m\vec{a} \tag{3.17}$$
$$a = \frac{-kx}{m} \tag{3.18}$$

$\vec{a}$ is the acceleration of the mass (in m/s^2)
k is the force constant of the spring (in N/m)
$\vec{x}$ is the displacement of the mass from its equilibrium position (in m)
m is the mass of the object that is attached to the spring (in kg)

Remark. Because the acceleration is a vector, we need to make a direction convention to use the equation.

3.5.3 The period of the Simple Harmonic Motion

The y-component of the uniform circular motion is similar to the acceleration of the simple Harmonic Motion

For the object going around circle:

$$a_c = \frac{4\pi^2 R}{T^2} \tag{3.19}$$

For the mass on the end of the spring:

$$\vec{a} = -\frac{k\vec{x}}{m} \tag{3.19}$$

$$|\vec{a}| = \frac{kx}{m} \tag{3.20}$$

When the object is on the top/bottom of the perfect circular motion, the acceleration is equal to the magnitude of the acceleration of the object at the equilibrium position:

$$a_c = |a| \tag{3.20}$$

$$\frac{4\pi^2 R}{T^2} = \frac{kx}{m} \tag{3.21}$$

$$T = +/- \sqrt{\frac{m * 4\pi^2 R}{kx}} (\text{At this time } R = x) \tag{3.22}$$

$$T = 2\pi * \sqrt{\frac{m}{k}} \tag{3.23}$$