

Kinetic and Potential Energy

Purpose

1. To learn about conservative forces in relation to potential energy.
2. To be introduced to Kinetic energy and Mechanical energy.
3. To study the effect of a non-conservative force, *Friction force*.

The work, W done by a force is defined in physics as the product of the force and the change in position along the direction of the force:

$$W = Fd \quad (1)$$

Its unit is Newton times meter, $N \cdot m$. This unit is called Joules, J .

When an external force does work against a conservative force, such that the velocity is kept constant during the motion, the work done is stored in the system as a potential energy that can be used later by the system. An example of a conservative force is gravitational force. See figure 1. The force of gravity is equal to mg . To lift the mass, m to the top of the cliff at a constant velocity (zero acceleration), the external force has to be equal and opposite to the downwards force of gravity mg . The work done by this external force is Fd , which here is $mg\Delta h$. Since gravity is a conservative force, this work is stored in the system as a change in potential energy known as change in Gravitational potential energy, ΔGPE :

$$\Delta GPE = mg\Delta h \quad (2)$$

Note that only the change in gravitational potential energy is meaningful since this change is the work done by the external force referred to above. We can take the reference, zero, of gravitational potential energy at any point, provided that we use the correct Δh for the change in height for the change in gravitational potential energy.

As mentioned above, this stored change in gravitational potential energy, ΔGPE can be used again. If the mass is released from the top of the cliff, it will fall, and as it is falling its speed will be increasing. Energy associated with speed of an object is called Kinetic energy KE . Kinetic energy, KE is defined as

$$KE = \frac{1}{2} mv^2 \quad (3),$$

where v is the speed of the object. As the mass is falling, its speed is increasing, and therefore its kinetic energy is increasing. Where is this energy coming from? It is taking from the stored GPE . Notice that as the object is falling, the height is decreasing and so is the GPE . The amount of GPE spent is equal to the amount of KE gained at each point. The sum of the GPE and the KE is called the Mechanical energy, ME :

$$ME = GPE + KE \quad (4)$$

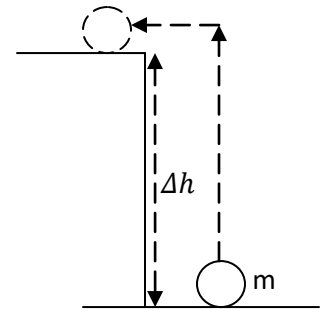


Figure 1: Work done against gravity is stored as GPE

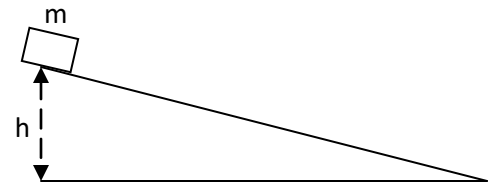


Figure 2: A mass sliding down an incline

Notice that at the top when the mass was at rest, $KE = 0 J$, since the mass is at rest, then the ME is equal to the Initial GPE . Similarly, when h becomes zero at the bottom, the mechanical energy, $ME = \text{final } KE$. We conclude that for a falling mass (if we ignore air resistance) the mechanical energy has a constant value.

Consider figure 2. If a mass slides down an incline, and if the incline is frictionless, then as it is sliding the gravitational potential energy, GPE is being converted to kinetic energy, KE . And at every point the Mechanical energy, $ME = GPE + KE$, as mentioned in eqn. 4 above. At the top of the incline, the mass is still at rest, so the Mechanical energy $ME = \text{initial } GPE$. At the bottom of the incline, the gravitational potential energy, GPE would be all converted to kinetic energy, KE , where the object has attained its maximum speed. So the Mechanical energy, $ME = \text{final } KE$. So again, we conclude that for a **frictionless** incline, the ME has a constant value at every point.

The friction force that a surface exerts on an object sliding or attempting to slide on the surface is defined as

$$F_{fr} = \mu N \quad (5)$$

where μ is called the coefficient of friction, and N is the normal force, which is the force by the surface on the object and perpendicular to the surface. Friction force is non-conservative. The work done by friction is **not** stored but is dissipated as thermal energy (heat) to the environment. Using equation 1, the work done by the friction force is equal to

$$-F_{fr}d = -\mu Nd \quad (6)$$

The negative sign is because the friction force always has a direction opposite to the motion, so it opposes the change in position. If the incline in figure 2 has friction, then as the object is sliding down, its gravitational potential energy is converted partly to kinetic energy and partly to thermal energy, so the share of kinetic energy here is less than for the case of a frictionless incline. We say that friction consumes part of the energy. And since mechanical energy is $ME = GPE + KE$, then the mechanical energy will be decreasing as the object slides down. The decrease in mechanical energy, ΔME is equal to the work done by friction:

$$\Delta ME = -F_{fr}d = -\mu Nd \quad (7)$$

For the block on the incline, the normal force, N is equal to $mg \cos \theta$. Do you know why? See figure 3. Notice in eqn. 7 that ΔME is **proportional to d** .

Running the experiment The data sheet is on page 4

Part 1: Block sliding down a frictionless incline

1) We will take the reference $GPE = \text{zero } J$ at the bottom of the incline where the height, $h = 0 m$. Open the simulator

http://physics.bu.edu/~duffy/HTML5/energy_rampslide.html

Note that the simulator uses a value of acceleration of gravity, $g = 10 m/s^2$. Keep all default values (coefficient of kinetic friction, $\mu = 0$). We will focus on the graph at the right that displays energy versus time.

2) The mass of the block $m = 3.3 Kg$, and the angle of the incline with the horizontal is approximately $\theta = 6.927^\circ$.

In figure 2, if the height of the incline at the left edge, $h = 24.3 cm$, calculate the initial gravitational potential energy using eqn. 2. (the reference $GPE = 0 J$ at the bottom of the incline where $h = 0 m$). Compare to the value given by the simulator (8 J).

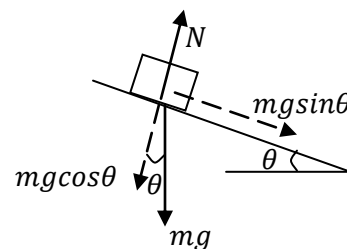


Figure 3: Resolution of the force of gravity for an object on an incline

- 3) If the block has a horizontal position $x = 100.2 \text{ cm}$, use the tangent trigonometric function and θ to calculate the height of the block at this point, call it h_2 . Now using h_2 and eqn. 2 calculate the GPE at this point (with respect to the zero GPE). What should the value of the KE be at this point? What should the value of the ME be at this point?
- 4) Now play the simulator and pause it before the horizontal position x becomes 100 cm . Note that the simulator displays the horizontal position as x . Advance in steps using the step advance **Step >>** till you reach the horizontal position $x = 100.2 \text{ cm}$. Record the time given by the simulator. Record the value of GPE and KE , and compare to your calculated value from step 3. Notice and record the value of the ME . Does the ME change?
- 5) Repeat steps 3 and 4 for $x = 150.3 \text{ cm}$. Notice that to find the height of the block at a point, you need the angle θ (given $= 6.927^\circ$) and the adjacent side of the incline which is $(200 - x) \text{ cm}$. Also remember that the units need to be in **meters**.

Part 2: Block sliding down an incline that has friction

- 1) Reset the simulator. Set the coefficient of kinetic friction, $\mu = 0.04$. Calculate the GPE at $x = 100.2 \text{ cm}$ and $x = 150.3 \text{ cm}$ using the method mentioned in step 3 and in step 5 of part 1. What do you notice about the values of GPE if you compare with those of part 1?
- 2) Run the simulator and at $x = 100.2 \text{ cm}$ and $x = 150 \text{ cm}$ (**or the closest to 150 cm**), record the GPE , KE and ME , and in addition, record the thermal energy, TE .
- 3) Using eqn. 6, calculate the thermal energy (energy dissipated due to friction) at the points where the horizontal position $x = 100.2 \text{ cm}$ and also again at $x = 150.3 \text{ cm}$. Notice that you will need the distance covered by the block **along the incline**. (You will need to use the cosine trigonometric function). Compare the values of the thermal energy dissipated to the value of the decrease in the mechanical energy, ME . Notice that the initial ME is equal to the initial GPE , ($= 8 \text{ J}$).
- 4) Now using the values of the change in ME and the initial value of the ME ($= 8 \text{ J}$), compute the ME of the block at the two points ($x = 100.2 \text{ cm}$ and $x = 150.3 \text{ cm}$).
- 5) Knowing the GPE and ME (the simulator measured values should be equal to your calculated values), find the KE at each of the 2 points ($x = 100.2 \text{ cm}$ and $x = 150.3 \text{ cm}$). Compare with the values of KE measured by the simulator.

Questions

- Suppose the force acting on an object and the velocity of the object are in opposite directions. Then the work done by the force is _____.
- In order to do work, a system must have _____.
- As a skier speeds up while gliding down a slope, _____ energy is converted into _____ energy.
- A weight lifter raises a 90 kg barbell 1.9 m. What is the potential energy gain of the barbell?

Data Sheet

Name:

Group:

Date experiment performed:

Part 1: Block sliding down a frictionless incline

Step 2) Calculated initial GPE (show your work):

Step 3) $x = 100.2 \text{ cm}$: Calculated GPE (show your work)=

Mechanical energy, $ME =$

Kinetic energy, $KE =$

Step 4) Simulator values

$x \text{ (cm)}$	$GPE \text{ (J)}$	$KE \text{ (J)}$	$ME \text{ (J)}$
100.2			

Step 5) $x = 150.3 \text{ cm}$: Calculated GPE (show your work)=

Mechanical energy, $ME =$

Kinetic energy, $KE =$

Simulator values

$x \text{ (cm)}$	$GPE \text{ (J)}$	$KE \text{ (J)}$	$ME \text{ (J)}$
150.3			

Part 2: Block sliding down an incline that has friction

Step 1) $x = 100.2 \text{ cm}$: Calculated $GPE =$

$x = 150 \text{ cm}$: Calculated $GPE =$

step 2) Simulator values

$x \text{ (cm)}$	$GPE \text{ (J)}$	$KE \text{ (J)}$	$ME \text{ (J)}$	$TE \text{ (J)}$
100.2				
150				

Step 3) $x = 100.2 \text{ cm}$. Calculation of TE (show your work):

$x = 150 \text{ cm}$. Calculation of TE (show your work):

Step 4)

$x \text{ (cm)}$	Distance covered along the incline, $d \text{ (m)}$	Calculated $ME \text{ (J)}$
100.2		
150		

Step 5

$x \text{ (cm)}$	Calculated $KE \text{ (J)}$	Compare to simulator values of $KE \text{ (J)}$
100.2		
150		

Answers to questions:

1)

3)

2)

4)