

# **Physics 111 - Class 9A**

# **PE & Energy Conservation**

October 31, 2022

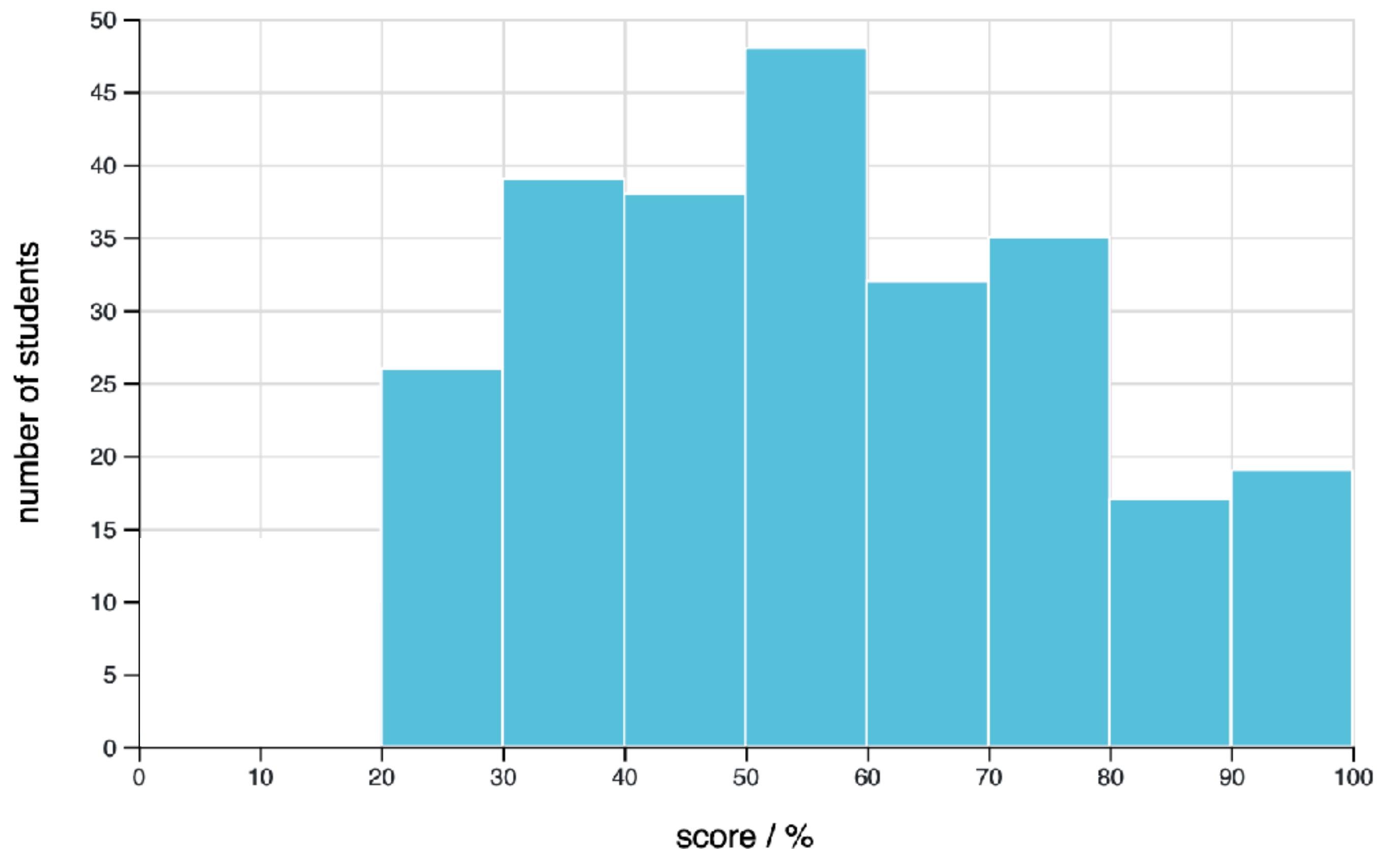
# Class Outline

- Logistics / Announcements
- Test 3 Reflection
- Chapter 8 Section Summary
- Clicker Questions (No time for CQs today!)
- Worked Problems

# Logistics/Announcements

- Lab this week: Lab 6
- HW8 due this week on Thursday at 6 PM
- Learning Log 8 due on Saturday at 6 PM
- HW and LL deadlines have a 48 hour grace period
- Test/Bonus Test: Bonus Test 3 is this Friday!

# Test 3 Reflection



Number of students

265

Mean score

54%

- Test 3 was pretty “tough but fair”
- Several questions from previous homework assignments
- Time wasn’t a factor (on average) ; median: 36 mins
- More conceptual questions than usual, because understanding Forces is very important
- A few misconceptions...

# Object in Circular Motion

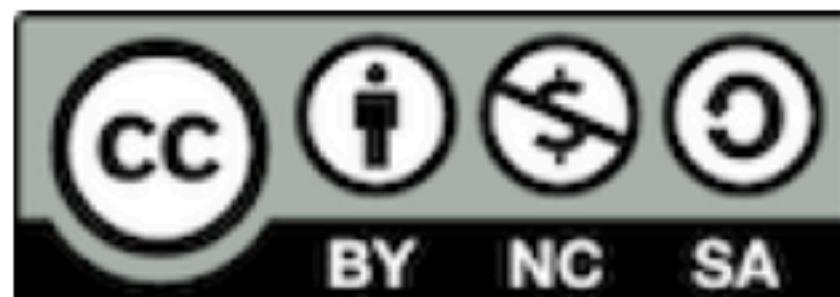
## Object In Circular Motion

Which of the following statements is always true about an object in circular motion?

- (a) The object's net acceleration is towards the centre of the circular motion
- (b) The net force on the object has a non-zero component towards the centre of the circle
- (c) The object's angular velocity is given by  $v^2/r$  where  $r$  is the radius of the circle
- (d) The object has constant kinetic energy

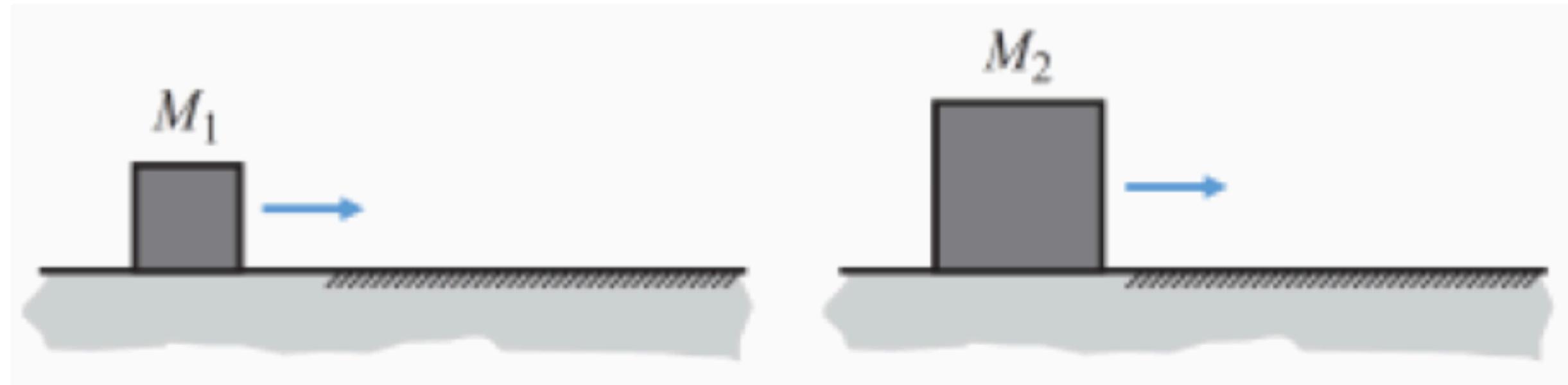
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Problem is licensed under the [CC-BY-NC-SA 4.0 license](#).



# Which Block stops first?

Two blocks,  $M_1 < M_2$ , having the same initial speed, move from a frictionless surface onto a surface having a coefficient of kinetic friction  $\mu_k$ .



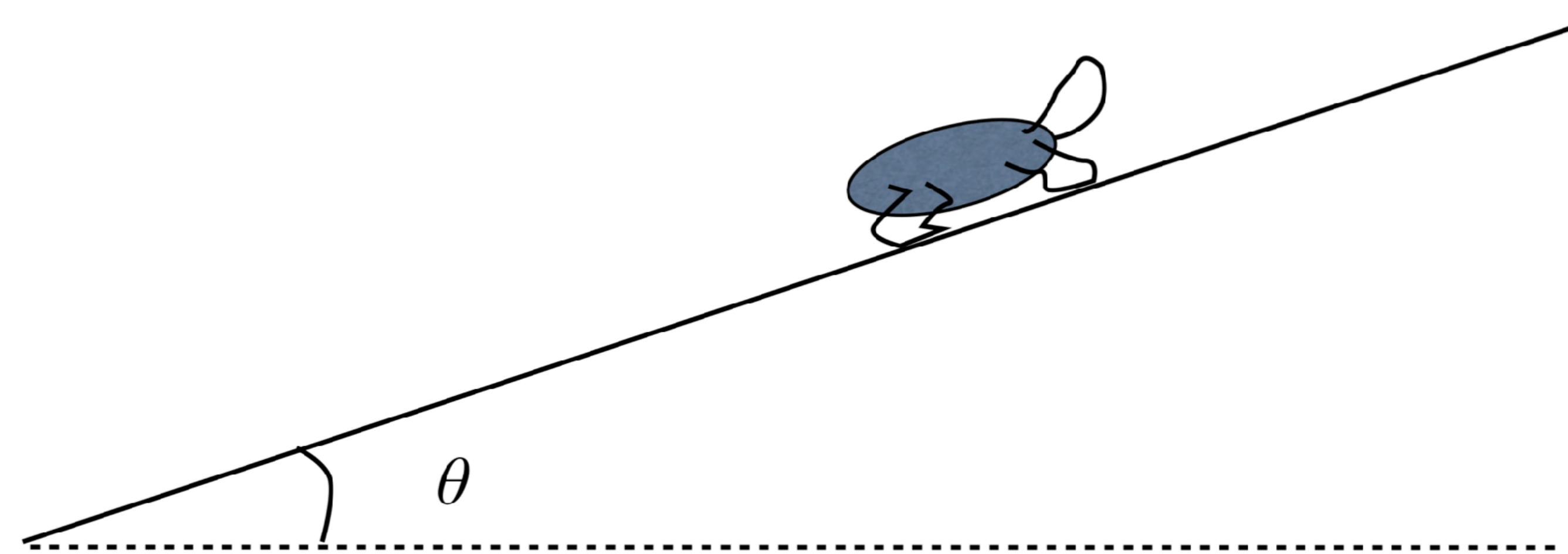
Which stops in a shorter distance?

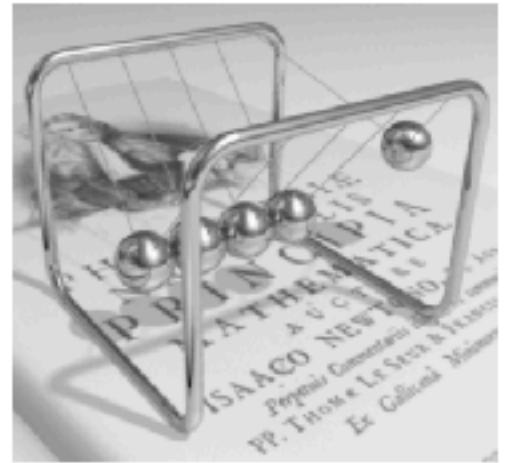
- (a)  $M_1$
- (b)  $M_2$
- (c) Cannot be determined without more information
- (d) Both stop in the same distance

# Turtle on a Log

A turtle lies on a log in the sun as shown in the figure below. The turtle has mass  $m$ , the log makes an angle  $\theta$  with respect to the horizontal and the coefficient of static friction between the turtle and the log is  $\mu_s$  (where  $\mu_s > \tan \theta$ ).

The magnitudes of the normal force,  $n$  and the frictional force  $f_s$  are:





## Physics 111

Search this book...

Unsyllabus

### ABOUT THIS COURSE

Course Syllabus (Official)

Course Schedule

Accommodations

How to do well in this course

### GETTING STARTED

Before the Term starts

After the first class

In the first week

Week 1 - Introductions!

### PART 1 - KINEMATICS

Week 2 - Chapter 2

Week 3 - Chapter 3

Week 4 - Chapter 4

### PART 2 - DYNAMICS

# Videos

Below are the assigned videos for this week. The videos are collapsible so once you're done with one, you can move to the next one. In the sidebar on the right, you can use the checklists to keep track of what's done.

## Required Videos

### 1. Introduction to Gravitational Potential Energy with Zero Line Examples

Introduction to Gravitational Potential Energy with Zero Line Examples

$PE_g = mgh$

m = mass of object

g = acceleration due to gravity

$[g_{Earth} = +9.81 \frac{m}{s^2}]$

$h$  = Vertical height above the horizontal zero line

zero line

Watch on YouTube

- Notes
- Direct link to Mr. P's page

Required Videos  
Optional Videos

### Checklist of items

- Video 1
- Video 2
- Video 3
- Video 4
- Video 5
- Video 6
- Video 7
- Video 8
- Video 9
- Video 10

# Introduction

 Table of contents



Search this book 

 My highlights

Preface

▼ Mechanics

- ▶ 1 Units and Measurement
- ▶ 2 Vectors
- ▶ 3 Motion Along a Straight Line
- ▶ 4 Motion in Two and Three Dimensions
- ▶ 5 Newton's Laws of Motion
- ▶ 6 Applications of Newton's Laws
- ▶ 7 Work and Kinetic Energy
- ▶ 8 Potential Energy and Conservation of Energy

**Introduction**

Mon

[8.1 Potential Energy of a System](#)

[8.2 Conservative and Non-Conservative Forces](#)

[8.3 Conservation of Energy](#)

[8.4 Potential Energy Diagrams and Stability](#)

[8.5 Sources of Energy](#)

▶ Chapter Review

▶ 9 Linear Momentum and Collisions

▶ 10 Fixed-Axis Rotation

▶ 11 Angular Momentum

▶ 12 Static Equilibrium and Elasticity

▶ 13 Gravity



**Figure 8.1** Shown here is part of a Ball Machine sculpture by George Rhoads. A ball in this contraption is lifted, rolls, falls, bounces, and collides with various objects, but throughout its travels, its kinetic energy changes in definite, predictable amounts, which depend on its position and the objects with which it interacts. (credit: modification of work by Roland Tanglao)

## Chapter Outline

[8.1 Potential Energy of a System](#)

[8.2 Conservative and Non-Conservative Forces](#)

[8.3 Conservation of Energy](#)

[8.4 Potential Energy Diagrams and Stability](#)

[8.5 Sources of Energy](#)

In George Rhoads' rolling ball sculpture, the principle of conservation of energy governs the changes in the ball's kinetic energy and relates them to changes and transfers for other types of energy associated with the ball's interactions. In this chapter, we introduce the important concept of potential energy. This will enable us to formulate

# **Monday's Class**

**8.1 Potential Energy of a System**

**8.4 Potential Energy Diagrams and Stability**

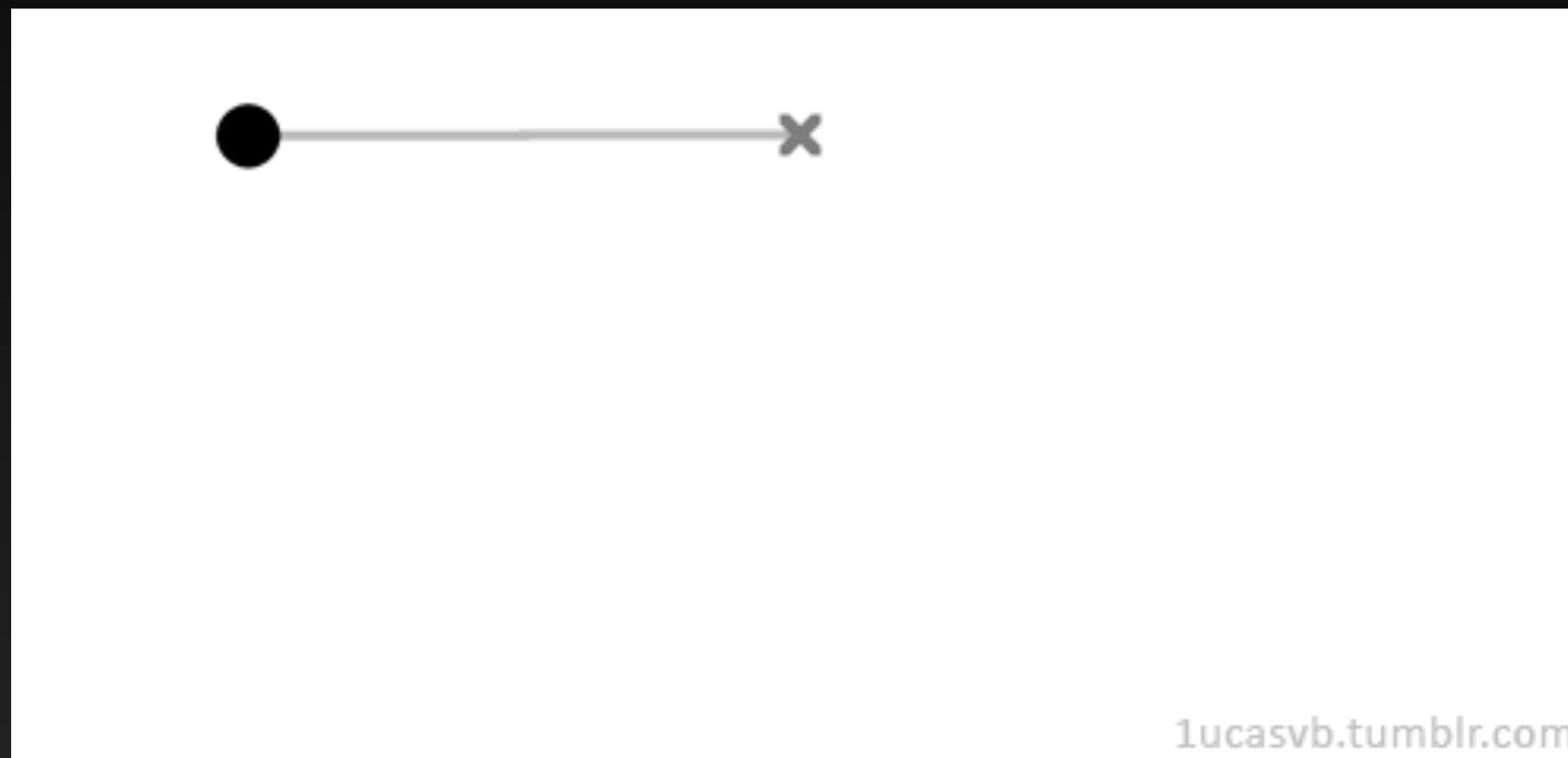
**8.5 Sources of Energy**

# Potential Energy

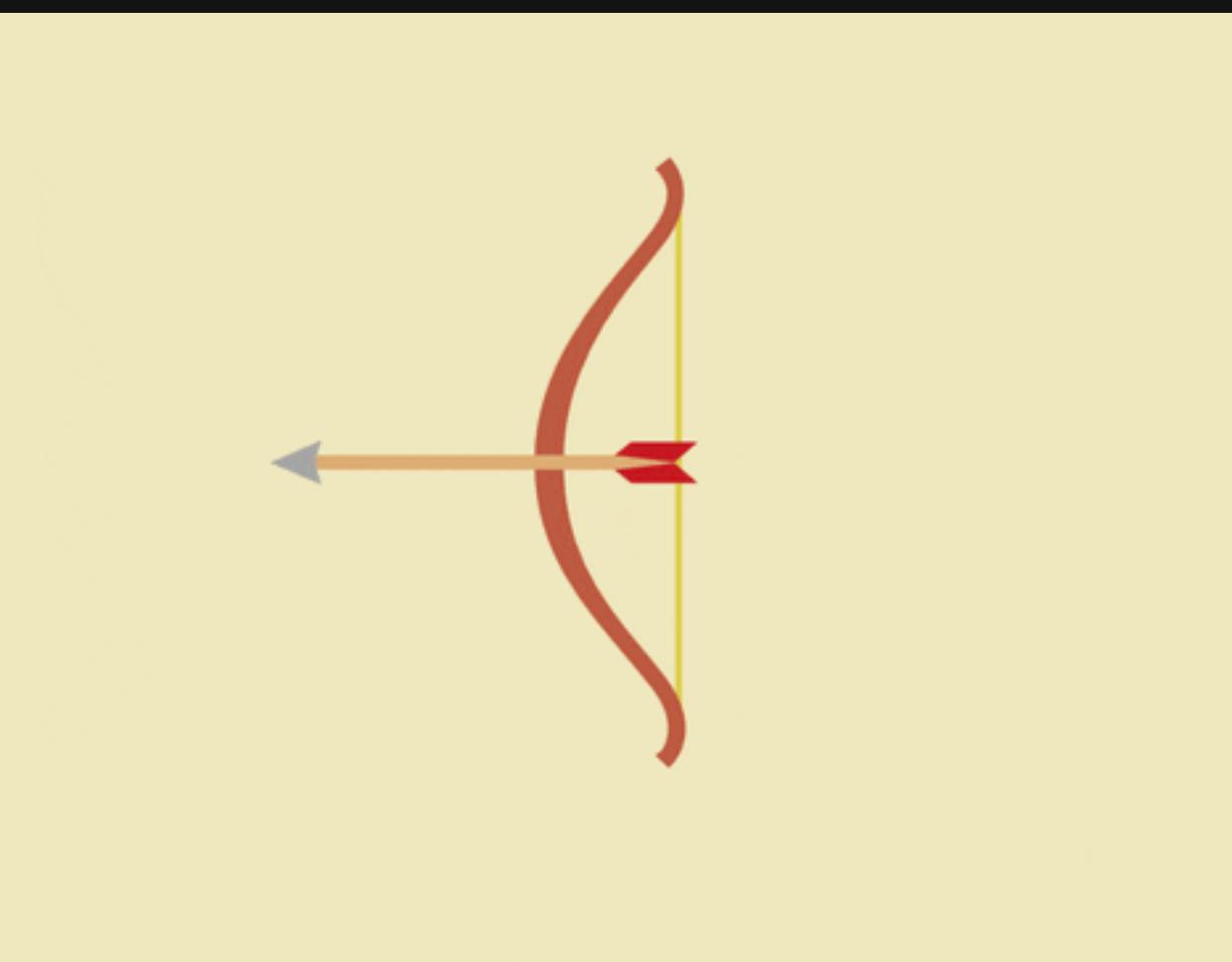
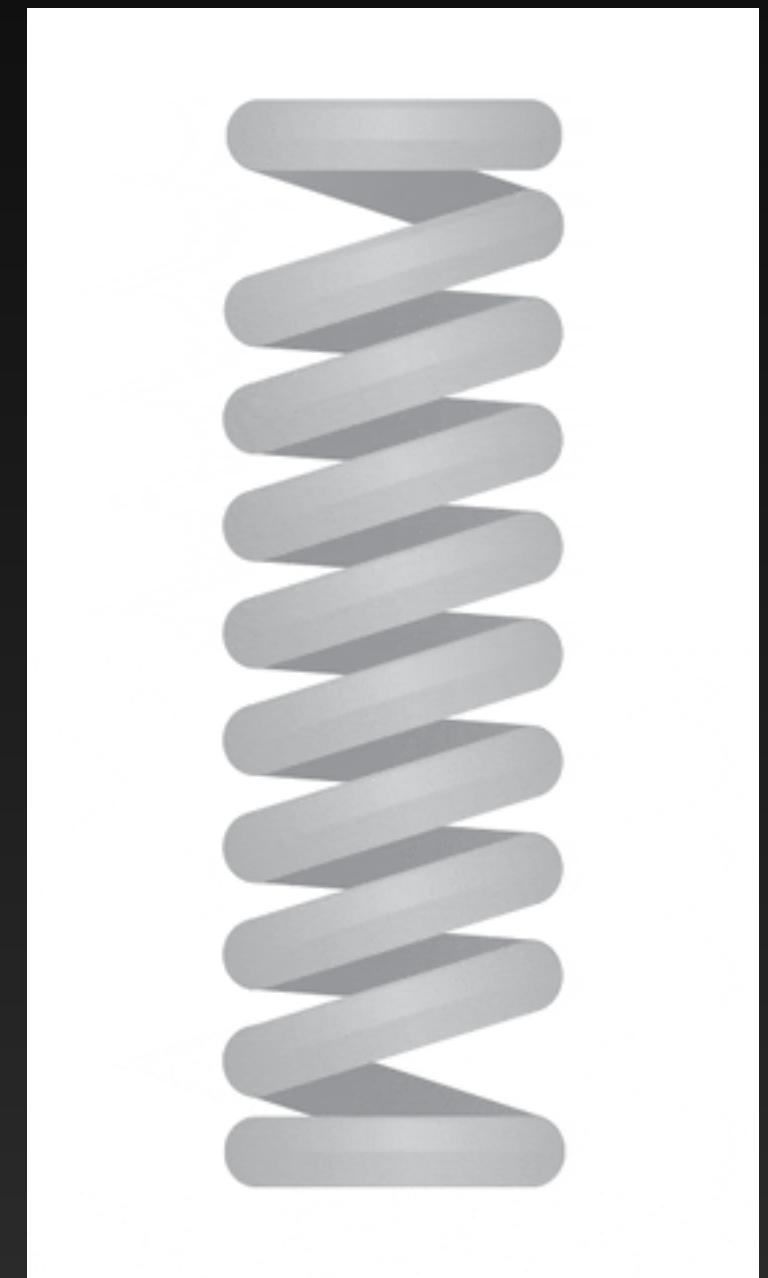
- Recall that “Kinetic Energy” was a characteristic of the object’s **mass** and **velocity**.
- “Potential Energy” is a different form of energy that’s characteristic of the object’s **position**.
- There are different forms of “Potential Energy”: Gravitational, Elastic/spring, Electrical, Nuclear...

# Examples of Potential Energy

## Gravitational Potential Energy



## Elastic Potential Energy



## Nuclear Potential Energy

# Definition of Potential Energy

Based on this scenario, we can define the difference of potential energy from point *A* to point *B* as the negative of the work done:

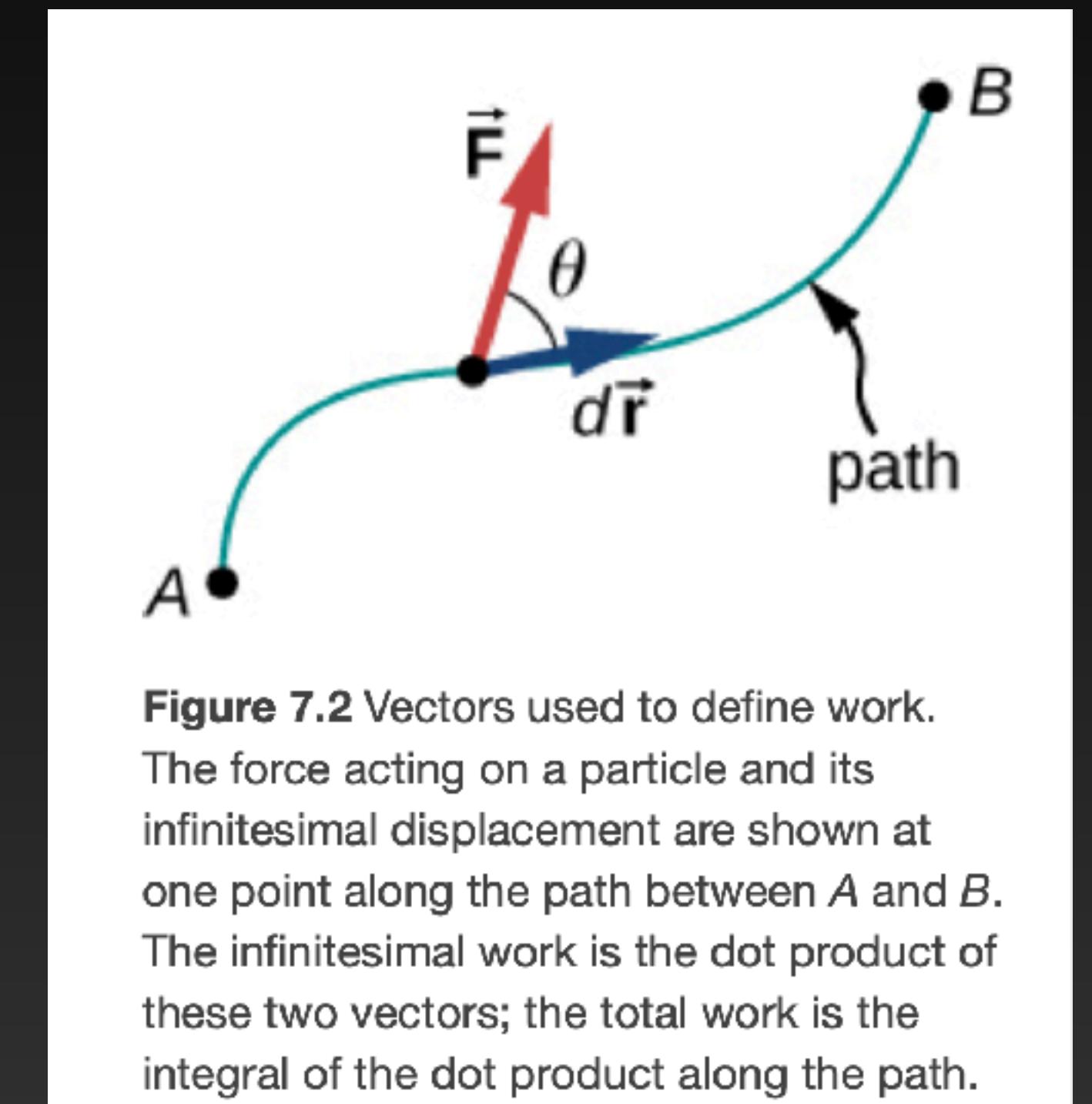
$$\Delta U_{AB} = U_B - U_A = -W_{AB}.$$

8.1

# Definition of Potential Energy from Work

Work is done whenever an applied (external) force causes displacement.

$$W = \int \vec{F} \cdot d\hat{\vec{r}}$$



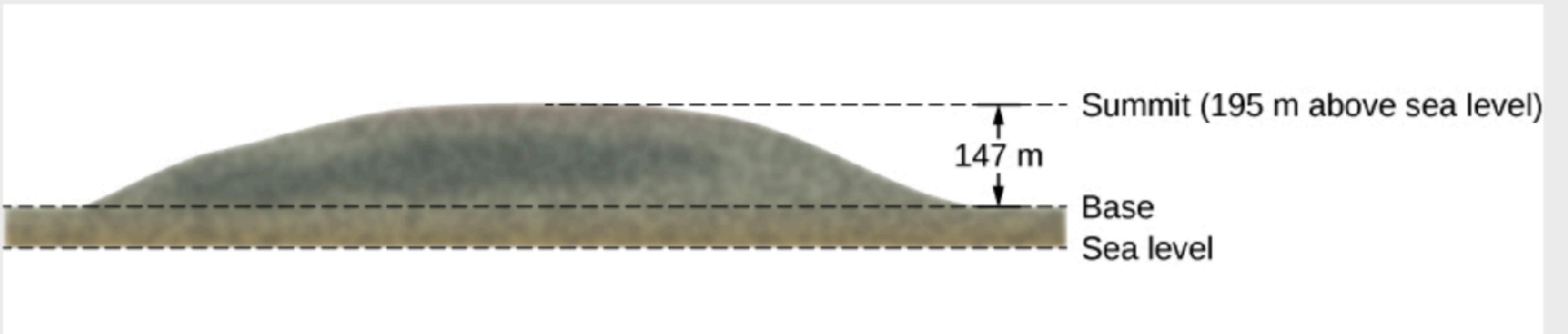
Change in Potential Energy is the negative of the work done...

$$\Delta U_{AB} = -W_{AB}$$

### EXAMPLE 8.2

#### Gravitational Potential Energy of a Hiker

The summit of Great Blue Hill in Milton, MA, is 147 m above its base and has an elevation above sea level of 195 m ([Figure 8.3](#)). (Its Native American name, *Massachusett*, was adopted by settlers for naming the Bay Colony and state near its location.) A 75-kg hiker ascends from the base to the summit. What is the gravitational potential energy of the hiker-Earth system with respect to zero gravitational potential energy at base height, when the hiker is (a) at the base of the hill, (b) at the summit, and (c) at sea level, afterward?

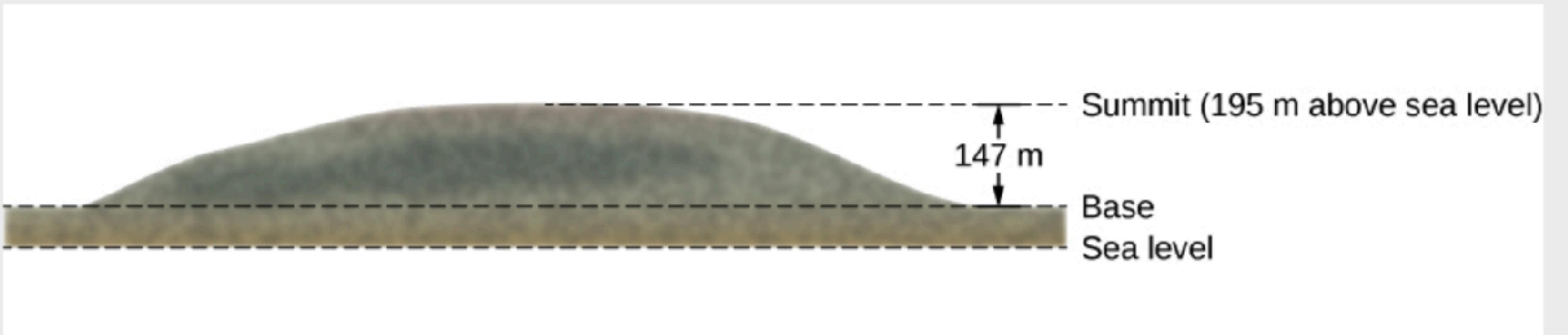


**Figure 8.3** Sketch of the profile of Great Blue Hill, Milton, MA. The altitudes of the three levels are indicated.

### EXAMPLE 8.2

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**Figure 8.3** Sketch of the profile of Great Blue Hill, Milton, MA. The altitudes of the three levels are indicated.

#### Strategy

First, we need to pick an origin for the  $y$ -axis and then determine the value of the constant that makes the potential energy zero at the height of the base. Then, we can determine the potential energies from [Equation 8.5](#), based on the relationship between the zero potential energy height and the height at which the hiker is located.



# Introduction to Gravitational Potential Energy with Zero Line Examples



Copy link

## Gravitational Potential Energy

$$PE_g \text{ [or } U_g]$$



$$PE_g = mgh$$

$m$  = mass of object

$g$  = acceleration due to gravity

$$\left[ g_{\text{Earth}} = +9.81 \frac{\text{m}}{\text{s}^2} \right]$$

$h$  = Vertical height above  
the horizontal zero line

## EXAMPLE 8.1

### Basic Properties of Potential Energy

A particle moves along the  $x$ -axis under the action of a force given by  $F = -ax^2$ , where  $a = 3 \text{ N/m}^2$ . (a) What is the difference in its potential energy as it moves from  $x_A = 1 \text{ m}$  to  $x_B = 2 \text{ m}$ ? (b) What is the particle's potential energy at  $x = 1 \text{ m}$  with respect to a given 0.5 J of potential energy at  $x = 0$ ?

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A particle moves along the  $x$ -axis under the action of a force given by  $F = -ax^2$ , where  $a = 3 \text{ N/m}^2$ . (a) What is the difference in its potential energy as it moves from  $x_A = 1 \text{ m}$  to  $x_B = 2 \text{ m}$ ? (b) What is the particle's potential energy at  $x = 1 \text{ m}$  with respect to a given 0.5 J of potential energy at  $x = 0$ ?

**Solution**

- a. The work done by the given force as the particle moves from coordinate  $x$  to  $x + dx$  in one dimension is

$$dW = \vec{F} \cdot d\vec{r} = Fdx = -ax^2dx.$$

Substituting this expression into [Equation 8.1](#), we obtain

$$\Delta U = -W = \int_{x_1}^{x_2} ax^2dx = \frac{1}{3}(3 \text{ N/m}^2)x^3 \Big|_{1 \text{ m}}^{2 \text{ m}} = 7 \text{ J.}$$

- b. The indefinite integral for the potential energy function in part (a) is

$$U(x) = \frac{1}{3}ax^3 + \text{const.},$$

and we want the constant to be determined by

$$U(0) = 0.5 \text{ J.}$$

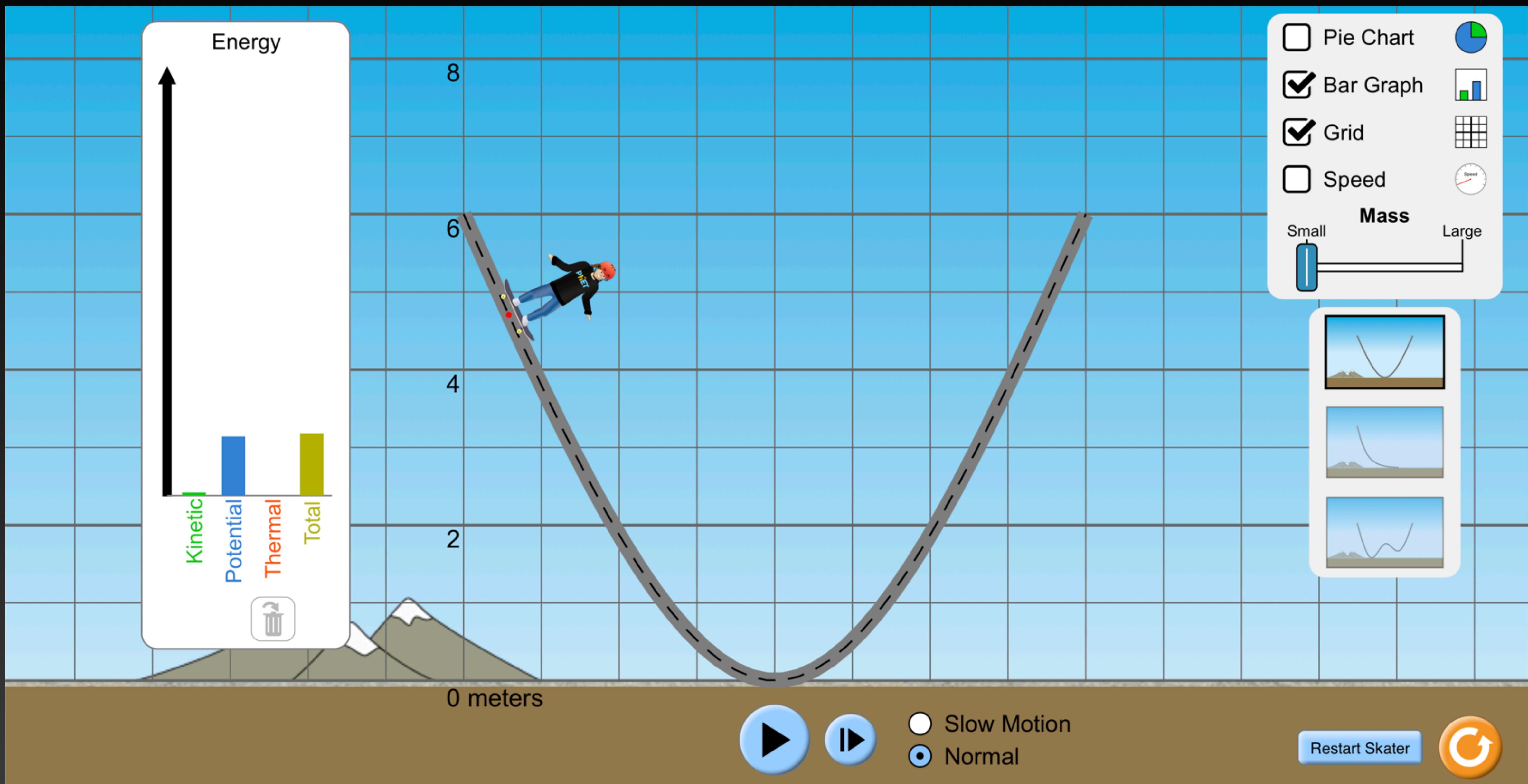
Thus, the potential energy with respect to zero at  $x = 0$  is just

$$U(x) = \frac{1}{3}ax^3 + 0.5 \text{ J.}$$

Therefore, the potential energy at  $x = 1 \text{ m}$  is

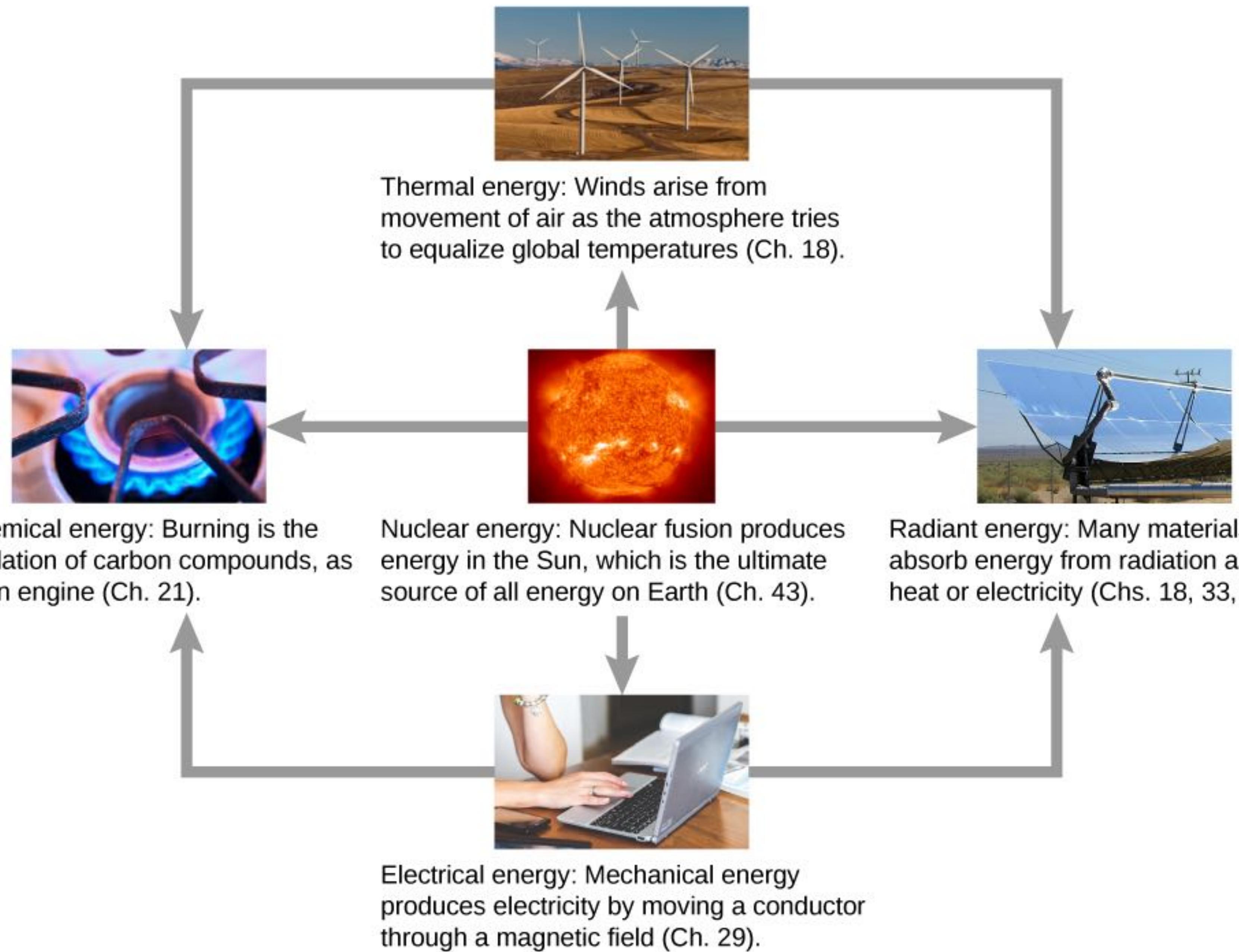
$$U(1 \text{ m}) = \frac{1}{3}(3 \text{ N/m}^2)(1 \text{ m})^3 + 0.5 \text{ J} = 1.5 \text{ J.}$$

# Energy Skatepark



# Energy Skatepark

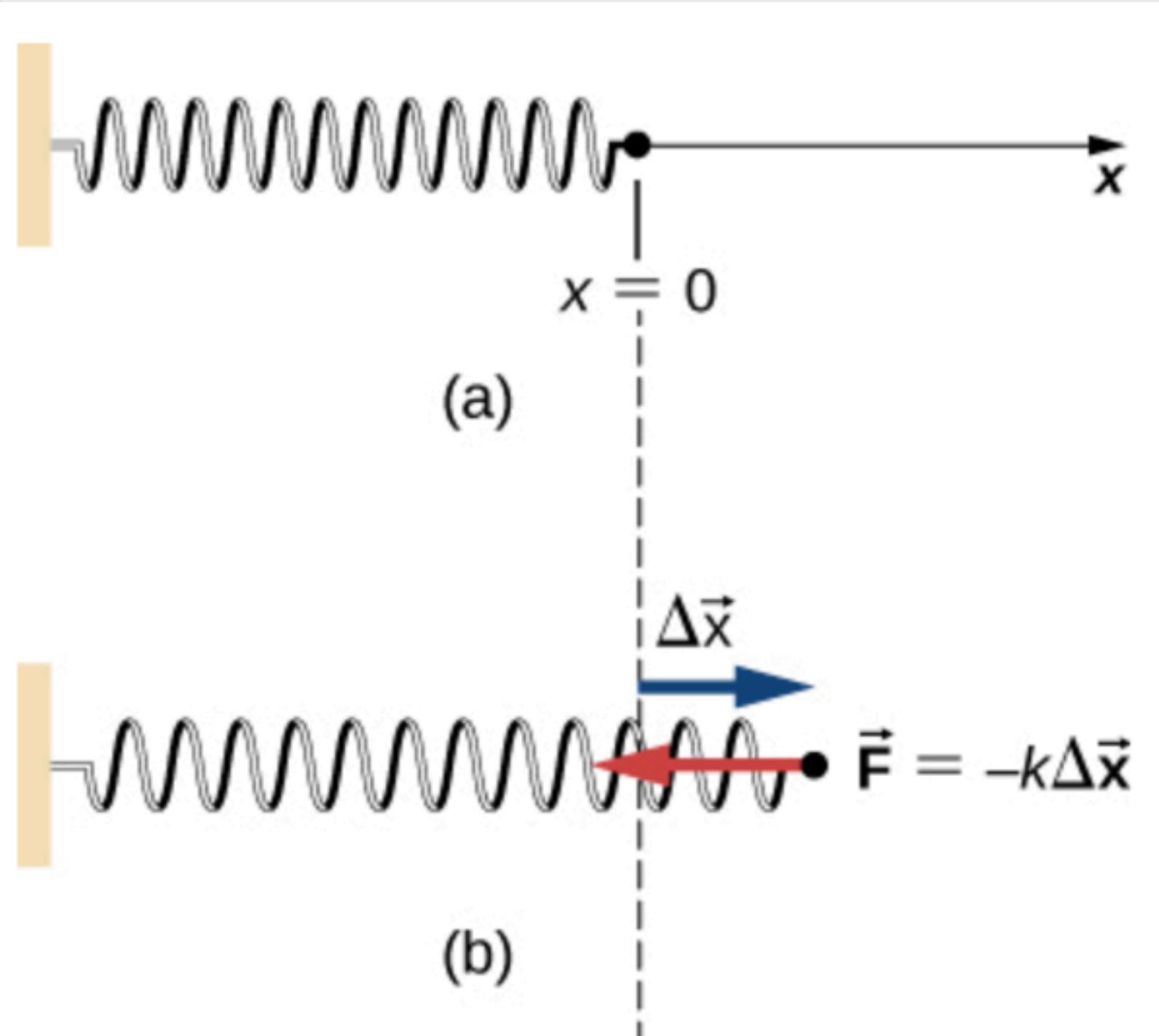
# Energy Types



## EXAMPLE 7.5

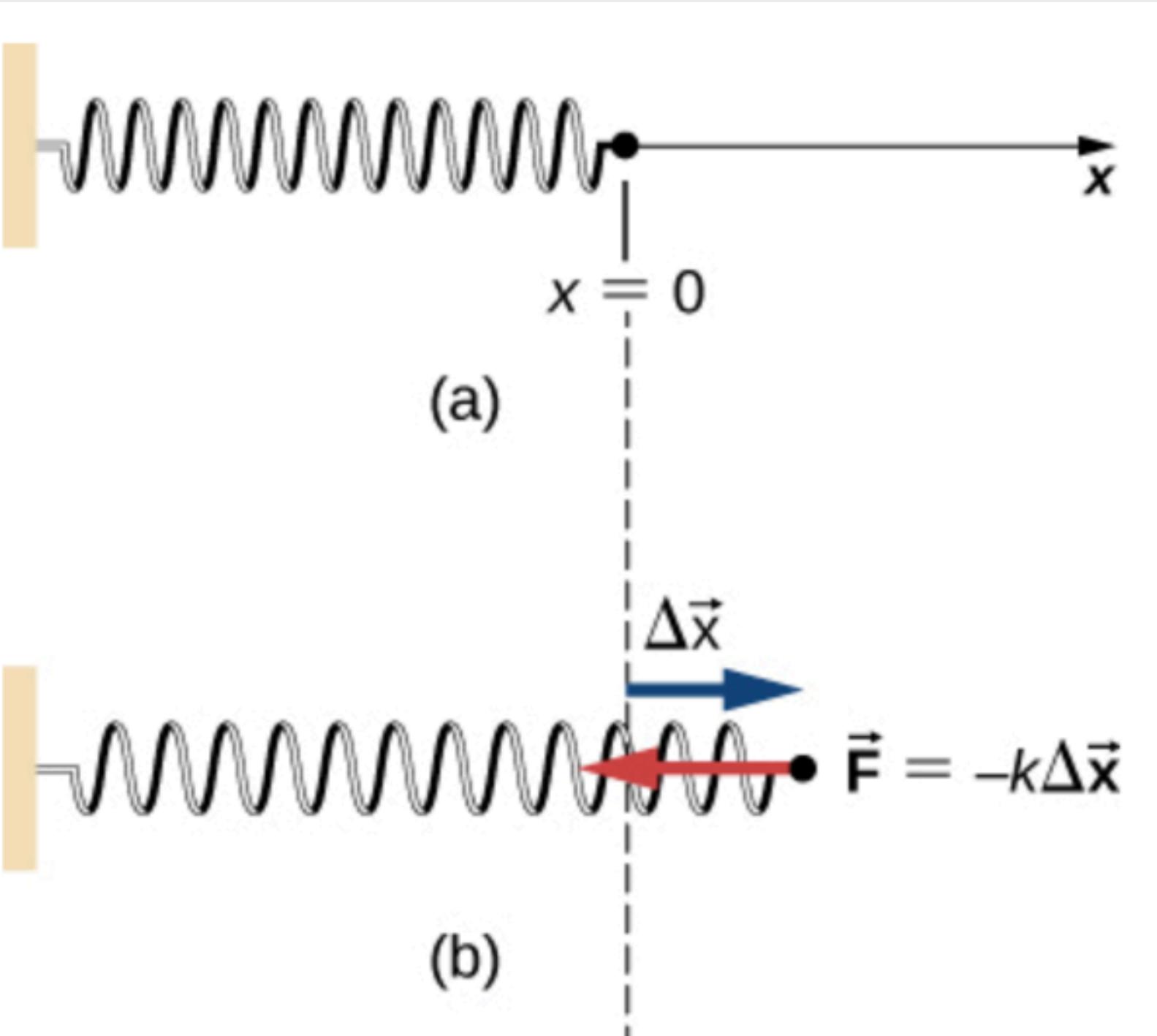
### Work Done by a Spring Force

A perfectly elastic spring requires 0.54 J of work to stretch 6 cm from its equilibrium position, as in [Figure 7.7\(b\)](#). (a) What is its spring constant  $k$ ? (b) How much work is required to stretch it an additional 6 cm?



**EXAMPLE 7.5****Work Done by a Spring Force**

A perfectly elastic spring requires 0.54 J of work to stretch 6 cm from its equilibrium position, as in [Figure 7.7\(b\)](#). (a) What is its spring constant  $k$ ? (b) How much work is required to stretch it an additional 6 cm?

**Strategy**

Work “required” means work done against the spring force, which is the negative of the work in [Equation 7.5](#), that is

$$W = \frac{1}{2}k(x_B^2 - x_A^2).$$

For part (a),  $x_A = 0$  and  $x_B = 6\text{cm}$ ; for part (b),  $x_B = 6\text{cm}$  and  $x_B = 12\text{cm}$ . In part (a), the work is given and you can solve for the spring constant; in part (b), you can use the value of  $k$ , from part (a), to solve for the work.

**Solution**

- a.  $W = 0.54\text{ J} = \frac{1}{2}k[(6\text{ cm})^2 - 0]$ , so  $k = 3\text{ N/cm}$ .
- b.  $W = \frac{1}{2}(3\text{ N/cm})[(12\text{ cm})^2 - (6\text{ cm})^2] = 1.62\text{ J}$ .

**Significance**

Since the work done by a spring force is independent of the path, you only needed to calculate the difference in the quantity  $\frac{1}{2}kx^2$  at the end points. Notice that the work required to stretch the spring from 0 to 12 cm is four times that required to stretch it from 0 to 6 cm, because that work depends on the square of the amount of stretch from equilibrium,  $\frac{1}{2}kx^2$ . In this circumstance, the work to stretch the spring from 0 to 12 cm is also equal to the work for a composite path from 0 to 6 cm followed by an additional stretch from 6 cm to 12 cm. Therefore,

# Elastic Potential Energy

## Elastic potential energy

In [Work](#), we saw that the work done by a perfectly elastic spring, in one dimension, depends only on the spring constant and the squares of the displacements from the unstretched position, as given in [Equation 7.5](#). This work involves only the properties of a Hooke's law interaction and not the properties of real springs and whatever objects are attached to them. Therefore, we can define the difference of elastic potential energy for a spring force as the negative of the work done by the spring force in this equation, before we consider systems that embody this type of force. Thus,

$$\Delta U = -W_{AB} = \frac{1}{2}k(x_B^2 - x_A^2),$$

8.6

### EXAMPLE 8.3

#### Spring Potential Energy

A system contains a perfectly elastic spring, with an unstretched length of 20 cm and a spring constant of 4 N/cm. (a) How much elastic potential energy does the spring contribute when its length is 23 cm? (b) How much more potential energy does it contribute if its length increases to 26 cm?

### EXAMPLE 8.3

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#### Strategy

When the spring is at its unstretched length, it contributes nothing to the potential energy of the system, so we can use [Equation 8.7](#) with the constant equal to zero. The value of  $x$  is the length minus the unstretched length. When the spring is expanded, the spring's displacement or difference between its relaxed length and stretched length should be used for the  $x$ -value in calculating the potential energy of the spring.

#### Solution

- a. The displacement of the spring is  $x = 23 \text{ cm} - 20 \text{ cm} = 3 \text{ cm}$ , so the contributed potential energy is  $U = \frac{1}{2}kx^2 = \frac{1}{2}(4 \text{ N/cm})(3 \text{ cm})^2 = 0.18 \text{ J}$ .
- b. When the spring's displacement is  $x = 26 \text{ cm} - 20 \text{ cm} = 6 \text{ cm}$ , the potential energy is  $U = \frac{1}{2}kx^2 = \frac{1}{2}(4 \text{ N/cm})(6 \text{ cm})^2 = 0.72 \text{ J}$ , which is a 0.54-J increase over the amount in part (a).

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#### Significance

Calculating the elastic potential energy and potential energy differences from [Equation 8.7](#) involves solving for the potential energies based on the given lengths of the spring. Since  $U$  depends on  $x^2$ , the potential energy for a compression (negative  $x$ ) is the same as for an extension of equal magnitude.

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### Basic Properties of Potential Energy

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$$U(1 \text{ m}) = \frac{1}{3}(3 \text{ N/m}^2)(1 \text{ m})^3 + 0.5 \text{ J} = 1.5 \text{ J.}$$

# Key Equations

Difference of potential energy

$$\Delta U_{AB} = U_B - U_A = -W_{AB}$$

Potential energy with respect to zero of potential energy at  $\vec{r}_0$

$$\Delta U = U(\vec{r}) - U(\vec{r}_0)$$

Gravitational potential energy near Earth's surface

$$U(y) = mgy + \text{const.}$$

Potential energy for an ideal spring

$$U(x) = \frac{1}{2}kx^2 + \text{const.}$$

Work done by conservative force over a closed path

$$W_{\text{closed path}} = \int \vec{F}_{\text{cons}} \cdot d\vec{r} = 0$$

Condition for conservative force in two dimensions

$$\left( \frac{dF_x}{dy} \right) = \left( \frac{dF_y}{dx} \right)$$

Conservative force is the negative derivative of potential energy

$$F_l = -\frac{dU}{dl}$$

Conservation of energy with no non-conservative forces

$$0 = W_{nc,AB} = \Delta(K + U)_{AB} = \Delta E_{AB}.$$

# Clicker Questions

# CQ.9.1

Which activity requires a person to exert force on an object that causes the object to move but does not change the kinetic or potential energy of the object?

- a) moving an object to a greater height with acceleration
- b) moving an object to a greater height without acceleration
- c) carrying an object with acceleration at the same height
- d) carrying an object without acceleration at the same height

A

B

C

D

E

# CQ.9.1

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- a) moving an object to a greater height with acceleration
- b) moving an object to a greater height without acceleration
- c) carrying an object with acceleration at the same height
-  d) carrying an object without acceleration at the same height

**Detailed solution:** Carrying an object at a given height at a constant speed does not change the KE or PE because the speed and height do not change. Force is exerted to oppose the force of gravity.

A

B

C

D

E

# CQ.9.2

You are riding a bicycle up a gentle hill. It is fairly easy to increase your potential energy, but to increase your kinetic energy would be harder.

- a) True
- b) False

A

B

C

D

E

# CQ.9.2

You are riding a bicycle up a gentle hill. It is fairly easy to increase your potential energy, but to increase your kinetic energy would be harder.

- a) True
- b) False

**Detailed solution:** PE can be increased continuously by riding up a gentle hill. An increase in KE would require you to ride ever faster and faster. There is a limit to how fast you can ride, so eventually you would feel exhausted.

A

B

C

D

E

# CQ.9.3

How much work is done by gravity when a 7.64 kg boulder falls to the ground from the top of a 33.4 m tall cliff?

- a) 0.0 J, because gravity doesn't do work
- b) 2.24 J
- c) 26.0 J
- d) 2500 J

A

B

C

D

E

# CQ.9.3

How much work is done by gravity when a 7.64 kg boulder falls to the ground from the top of a 33.4 m tall cliff?

- a) 0.0 J, because gravity doesn't do work
- b) 2.24 J
- c) 26.0 J
-  d) 2500 J

**Detailed solution:** The work done will be equivalent to the gravitational potential energy before it falls: use  $mgh$ .

A

B

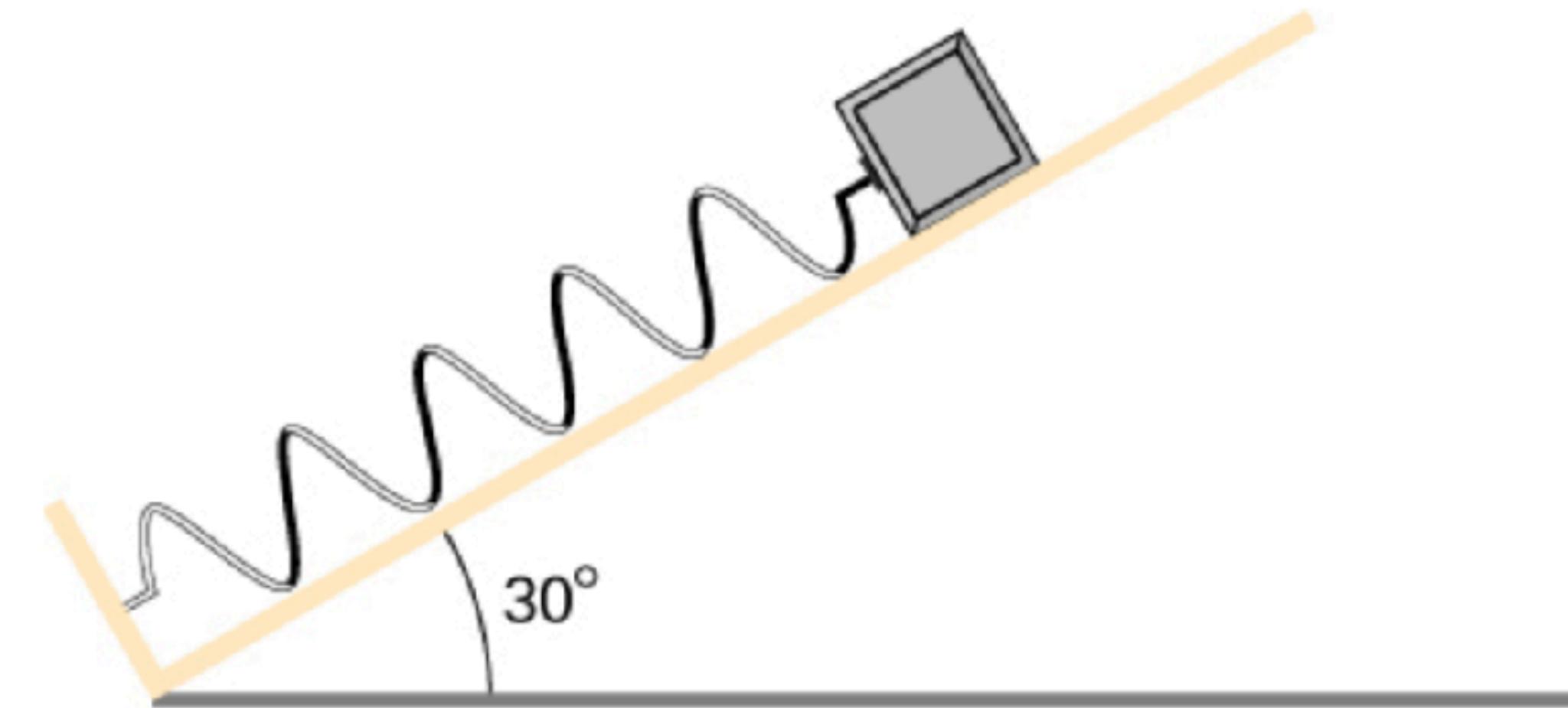
C

D

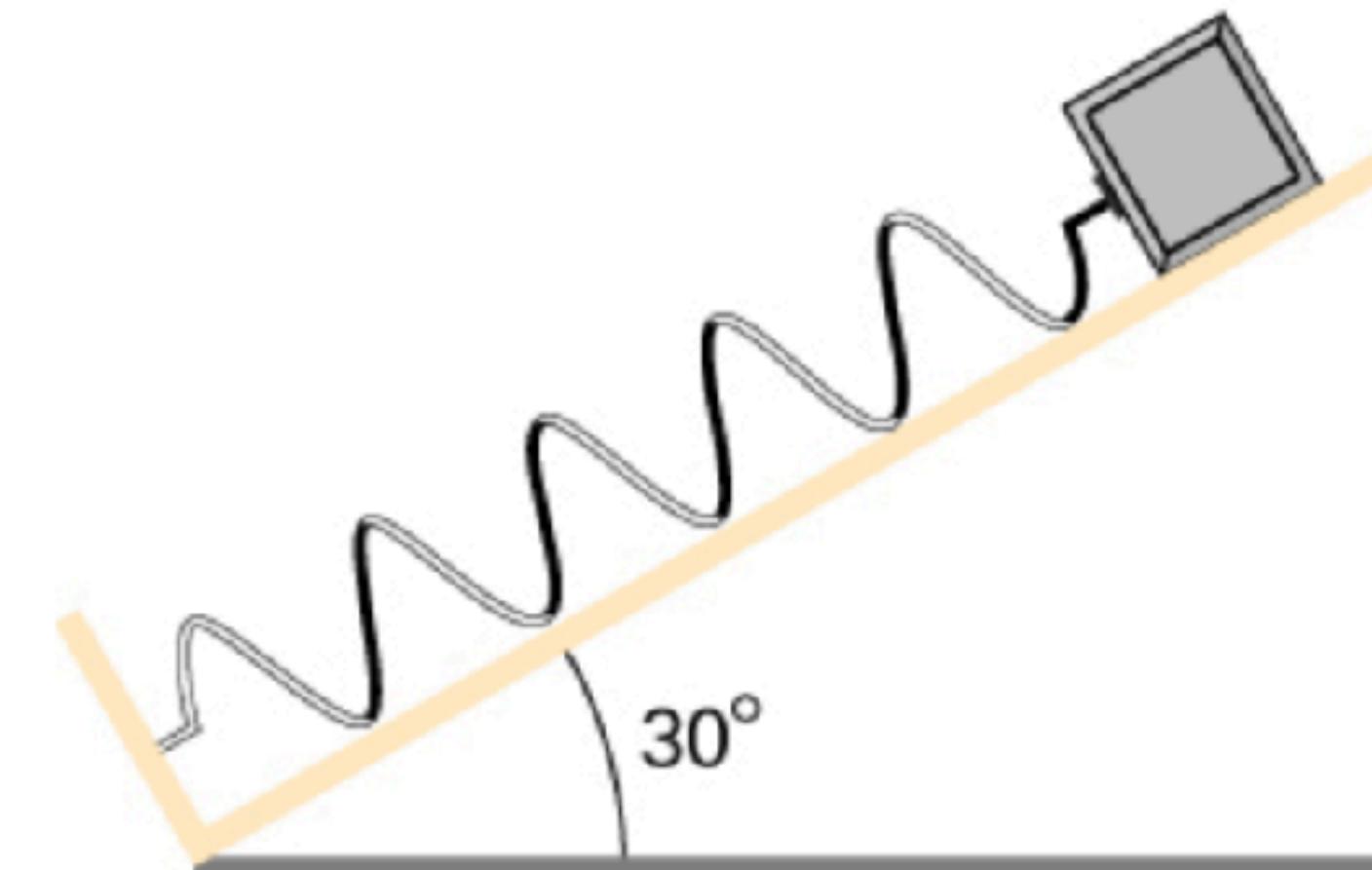
E

# Activity: Worked Problems

64 . A block of mass 500 g is attached to a spring of spring constant 80 N/m (see the following figure). The other end of the spring is attached to a support while the mass rests on a rough surface with a coefficient of friction of 0.20 that is inclined at angle of  $30^\circ$ . The block is pushed along the surface till the spring compresses by 10 cm and is then released from rest. (a) How much potential energy was stored in the block-spring-support system when the block was just released? (b) Determine the speed of the block when it crosses the point when the spring is neither compressed nor stretched. (c) Determine the position of the block where it just comes to rest on its way up the incline.



64 . A block of mass 500 g is attached to a spring of spring constant 80 N/m (see the following figure). The other end of the spring is attached to a support while the mass rests on a rough surface with a coefficient of friction of 0.20 that is inclined at angle of  $30^\circ$ . The block is pushed along the surface till the spring compresses by 10 cm and is then released from rest. (a) How much potential energy was stored in the block-spring-support system when the block was just released? (b) Determine the speed of the block when it crosses the point when the spring is neither compressed nor stretched. (c) Determine the position of the block where it just comes to rest on its way up the incline.



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$\theta = 30^\circ$

$M_R = 0.20$

Notice this interesting behaviour since this block is connected to a Spring!

a) PE in spring,  $\Delta x = 10\text{cm}$

$$P_{Es} = U_s = \frac{1}{2} k \Delta x^2 = \frac{1}{2} \cdot (80\text{N/m}) \cdot (0.1\text{m})^2$$

$$P_{Es} = 0.4\text{J}$$

b) Speed of block when  $\Delta x = 0$

We know that all of the  $P_{Es_0}$  must get converted into  $(KE + \text{Friction loss} + P_{EG})$

$$P_{Es_0} = KE + W_f + P_{EG}$$

$$KE = P_{Es_0} - W_f - P_{EG}$$

$$= P_{Es_0} - M_R Mg \cos\theta \cdot d - mg h$$

$$= P_{Es_0} - M_R mg \cos\theta \cdot d - mg d \sin\theta$$

$d = 0.1\text{m}$     $h = d \sin\theta$

c) Position of block at rest up the ramp

$V = 0$ , so  $KE = 0$ .

$$P_{Es_0} = KE^0 + W_f + P_{EG} + P_{Es_1}$$

$$= M_R Mg \cos\theta d +$$

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**See you next class!**

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