Physics 111 - Class 9B
PE & Energy Conservation

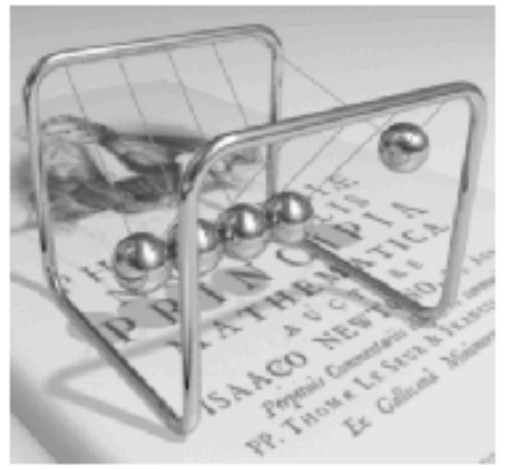
November 2, 2022

Class Outline

- Logistics / Announcements
- Conservation of Energy
- Clicker Questions
- Worked Problems
- One more thing: Bullet Block Problem

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!



Physics 111

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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

Required Videos

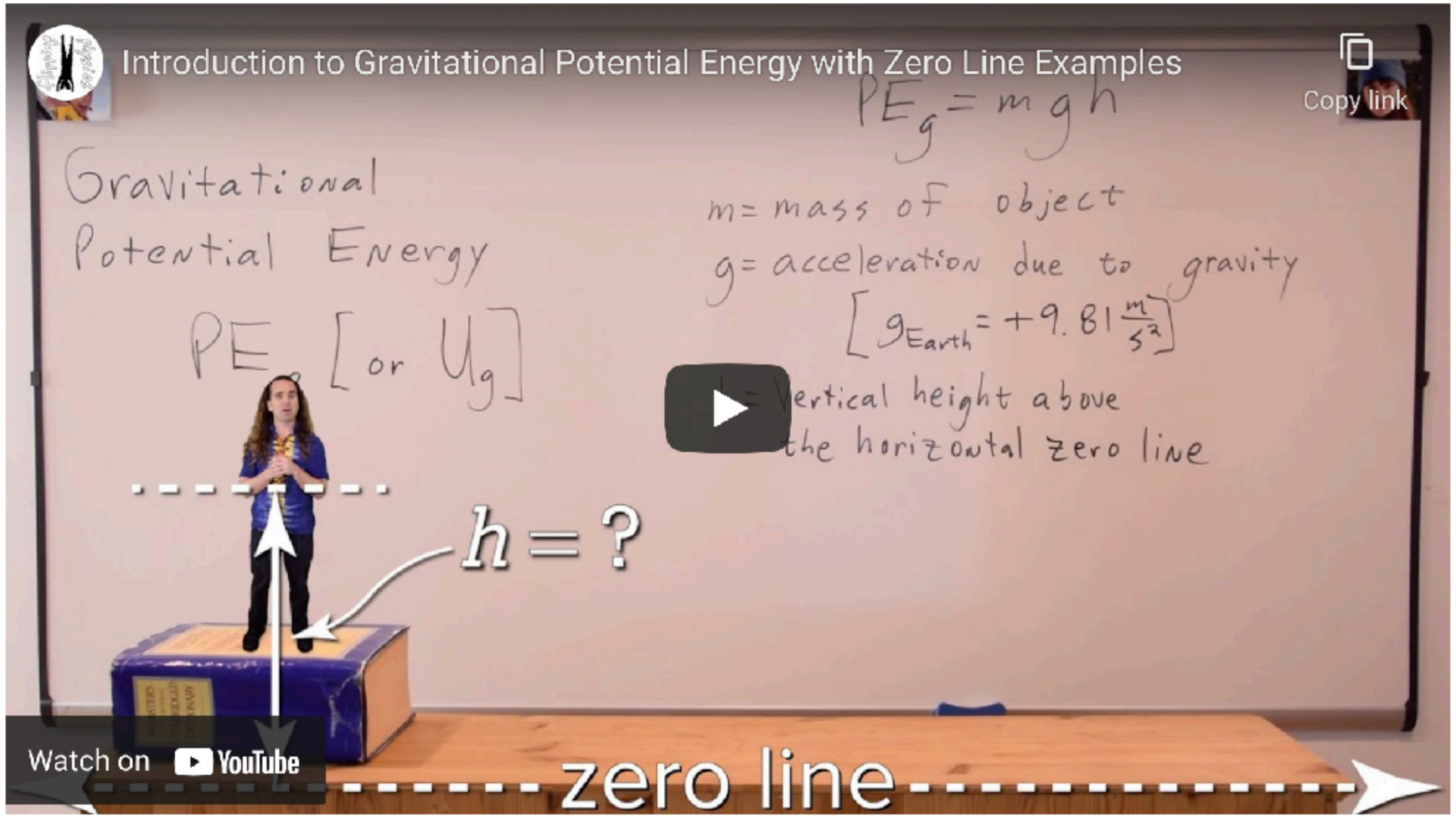
Optional Videos

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



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

Checklist of items

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

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My highlights

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)

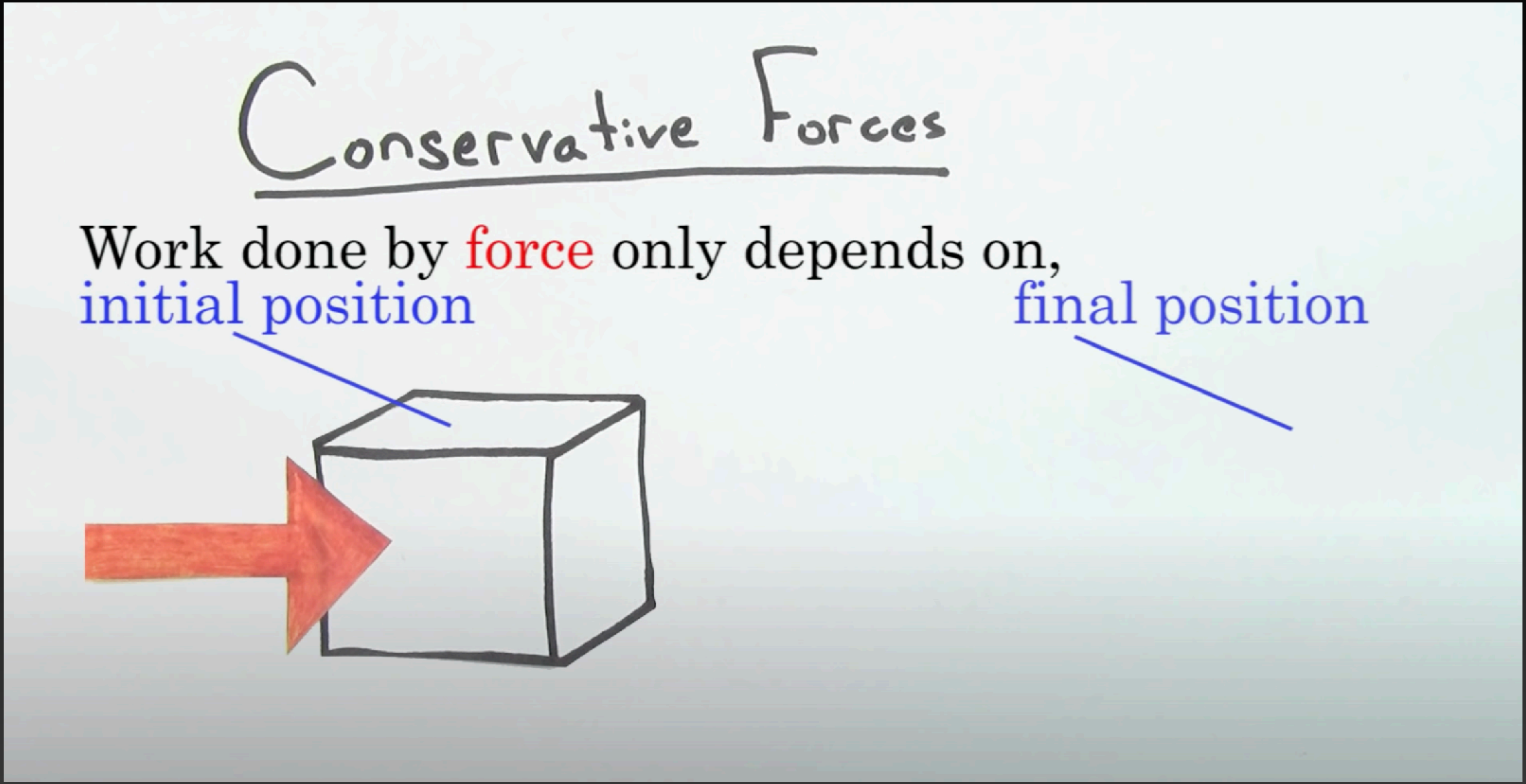
Chapter Outline

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

Friday's Class

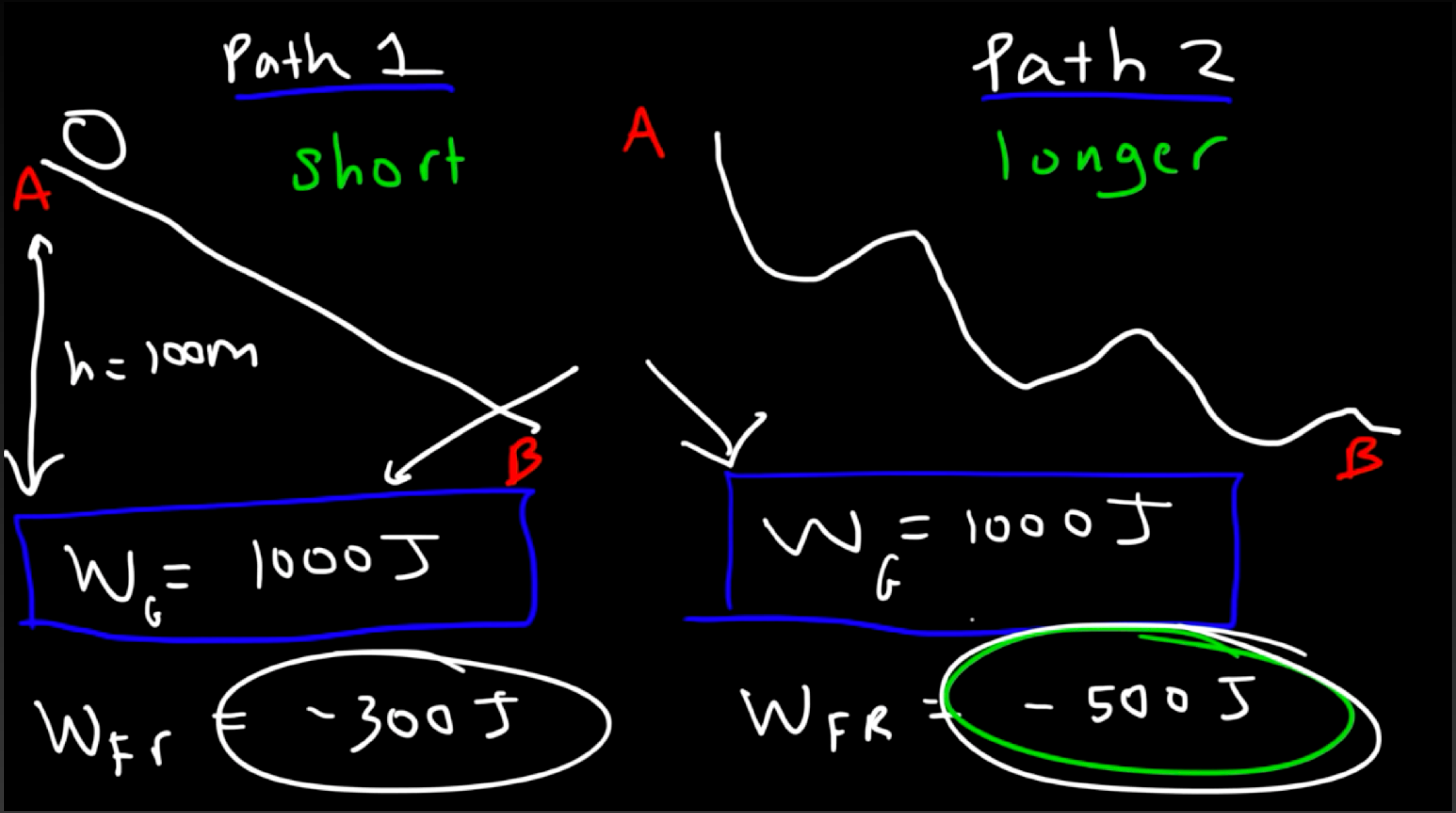
8.3 Conservation of Energy

Review: Conservative and Non-Conservative Forces



Source: Khan Academy

Review: Conservative and Non-Conservative Forces



Gravity: Conservative

Friction: NON-Conservative

Source: Organic Chemistry Tutor

Conservative and Non-Conservative Forces

Normal forces are nonconservative

For simplicity, consider a frictionless horizontal surface. Push a block, initially at rest at point A, through point B twice so that the block passes through B at two different speeds (figure 5). Only the horizontal normal force N that you apply does

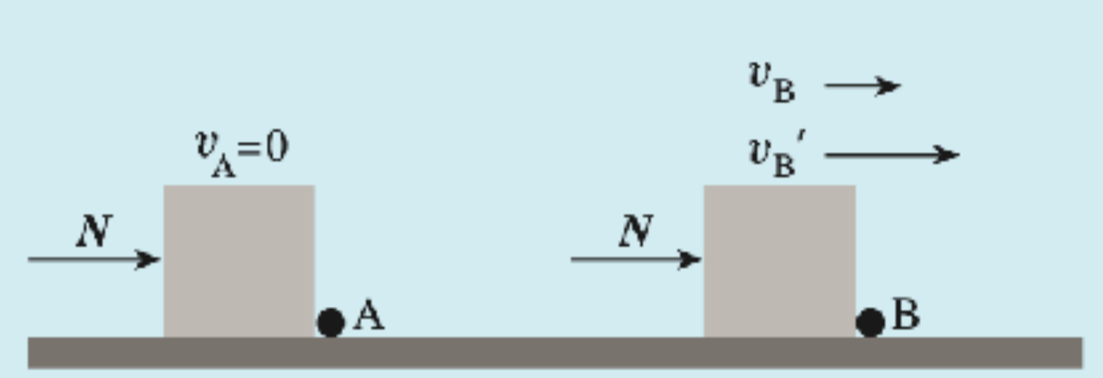


Figure 5. You can make a block initially at rest pass through point B with two different speeds and thus with two different kinetic energies by pushing it with a horizontal normal force. By the work–energy theorem, different kinetic energy changes imply that the work done by the normal force N between the two points is path-dependent.

work upon the block. According to the work–energy theorem, the total work upon the block equals its kinetic energy change. Here, different kinetic energy changes imply path-dependent work.

A normal force exhibits an important fundamental difference from a conservative force such as a spring force. While the force a spring exerts is determined just by the displacement of the end of the spring from its equilibrium position, you are free to apply the normal force of your choice to the box while you push the box from A to B. Thus, you are free to choose how much work your normal force does upon the box between A and B.

Tensions are nonconservative

Repeat the above argument for normal forces, except this time drag the block across the surface with a horizontal string instead of pushing it horizontally with your hand (figure 6).

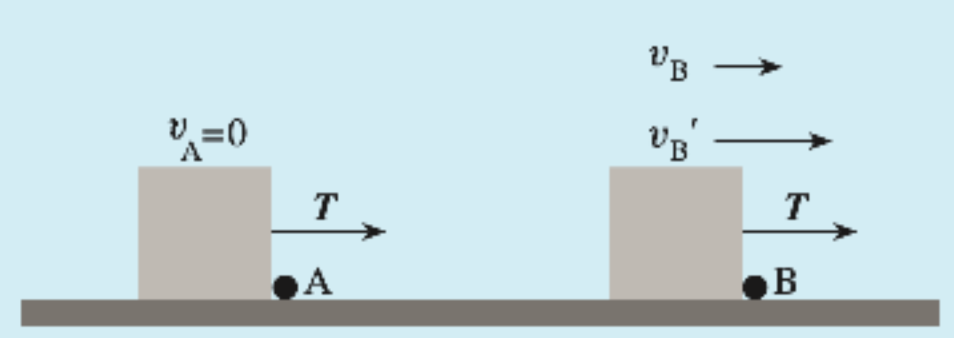


Figure 6. Tension T can cause a block initially at rest at point A to pass through point B with two different kinetic energies.

Kinetic friction is a nonconservative force

Suppose that points A and B lie on the surface of a horizontal table. First apply a horizontal force to push the block directly from A to B. Then apply a horizontal force to push the block from A to B along a longer path (figure 2). Since kinetic friction does more negative work in the second case, the work of kinetic friction is path dependent.

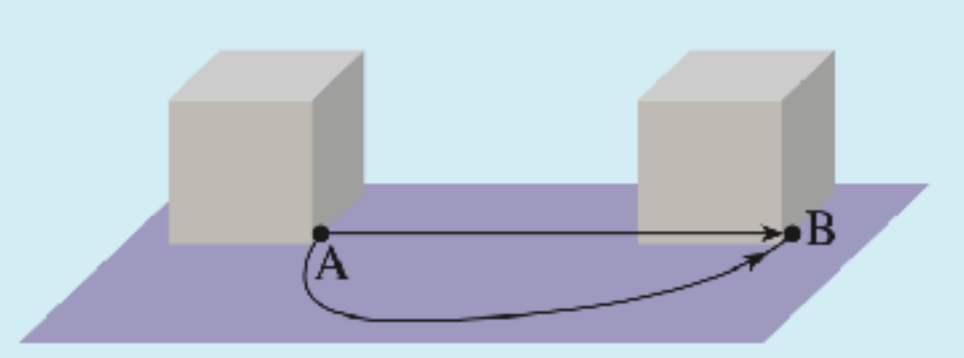


Figure 2. The work done by kinetic friction is more negative along the longer path from A to B.

Static friction is nonconservative

It may be surprising to students that static friction is capable of doing *any* work, but here's a case

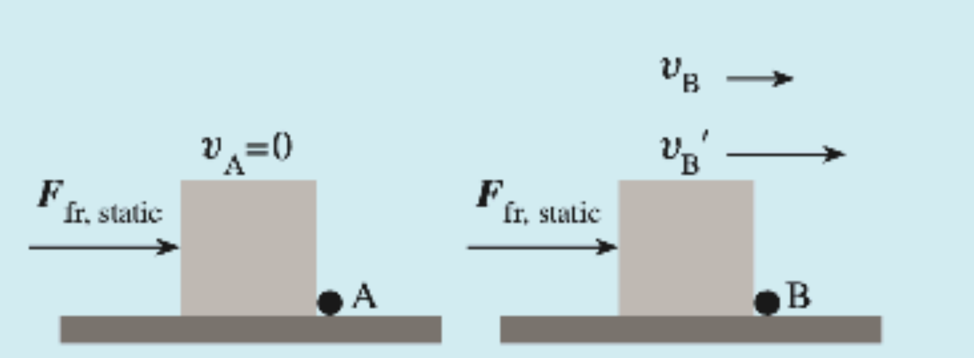


Figure 7. The static friction that a board exerts upon a block can cause the block to undergo two different kinetic energy changes between two points.

where it does. Just place a block on top of a board and hold the board horizontally by its ends. Start with the block at rest at point A. Then move the board and the block horizontally twice through point B so that the block passes through B with different speeds (figure 7). Be careful that the block doesn't slide on the board! Static friction from the board is the only horizontal force that acts upon the block. Different kinetic energy changes for the block along the two paths imply that the static friction from the board does different amounts of work upon the block along the two paths.

Spring forces are conservative

The work that a spring does upon an object attached to its end is given by

$$\begin{aligned} W &= \int_A^B F(x)\,dx \\ &= -k\int_A^B x\,dx \\ &= -\frac{k}{2}(B^2 - A^2). \qquad (1) \end{aligned}$$

There are countless ways to move the end of the spring from $x = A$ to $x = B$. You can move the end of the spring slowly or quickly from A to B. You can move the end of the spring from A to

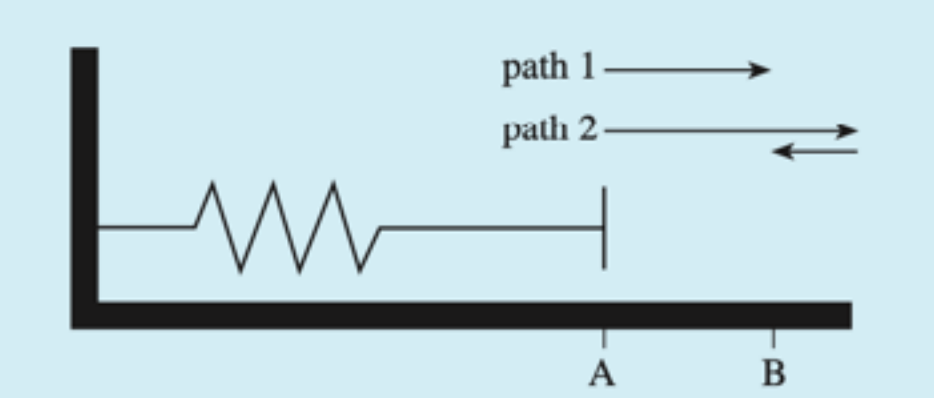


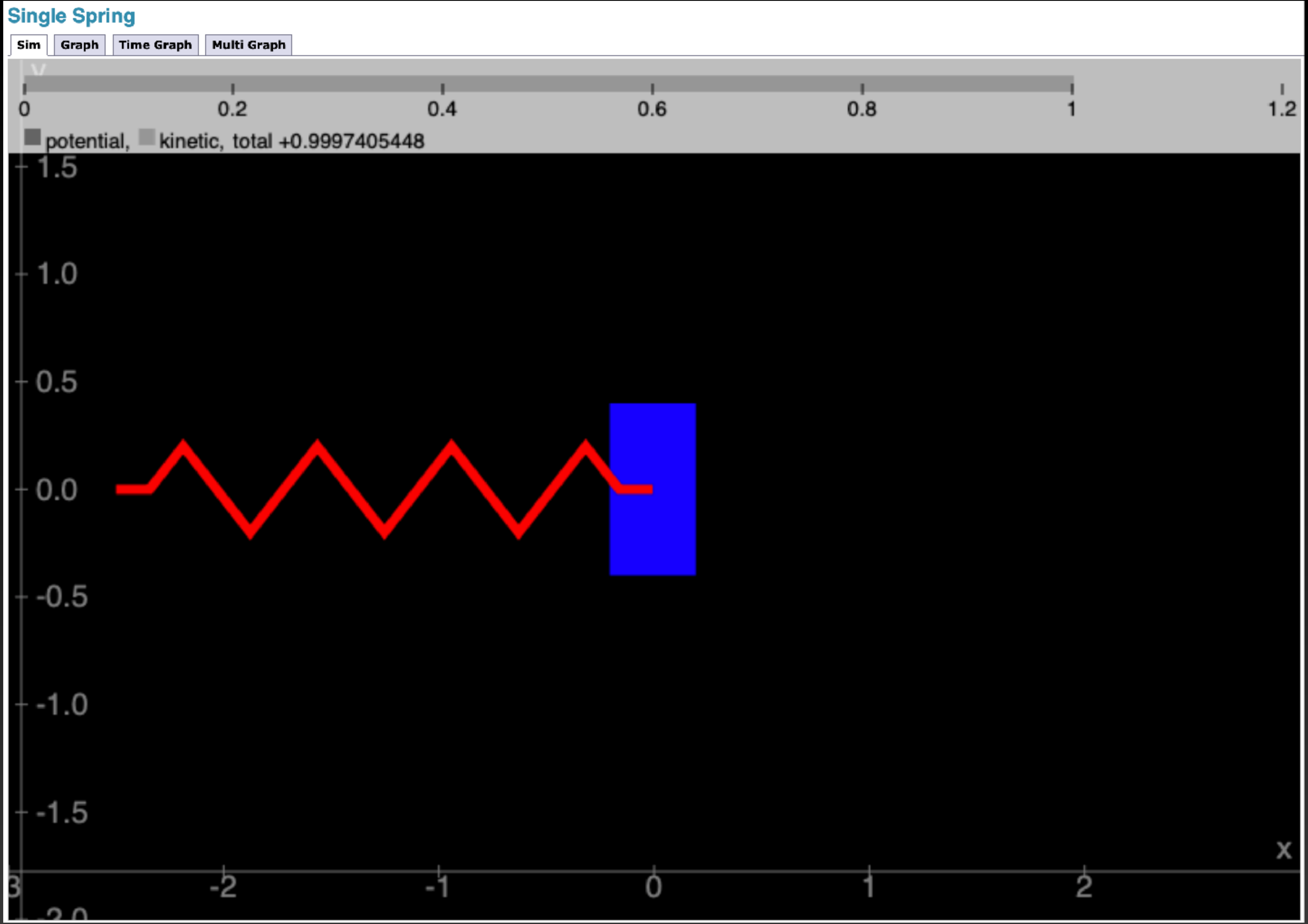
Figure 3. The value of the integral in equation (1) is independent of the path of the spring's end between point A and point B.

a point beyond B and then return the end of the spring to B (figure 3). Nothing about the integral in equation (1) depends upon the path from A to B, providing that Hooke's law is obeyed throughout the path.

Gravity is a conservative force

Since gravity's direction is straight down, an object's horizontal motion contributes nothing to the work upon an object as it moves from A to B. Thus gravity's net work ($+mgh$ if A is higher than B and $-mgh$ if B is higher than A) depends only upon the object's net vertical displacement and not upon its path from A to B (figure 1). (Work becomes $\pm GMm(1/r_B - 1/r_A)$ in a nonuniform gravitational field.)

Paper Reference: David Keeports, "The common forces: conservative or nonconservative?"



Energy in Springs

Source: Single Spring Simulation

Conservation of Energy

CONSERVATION OF ENERGY

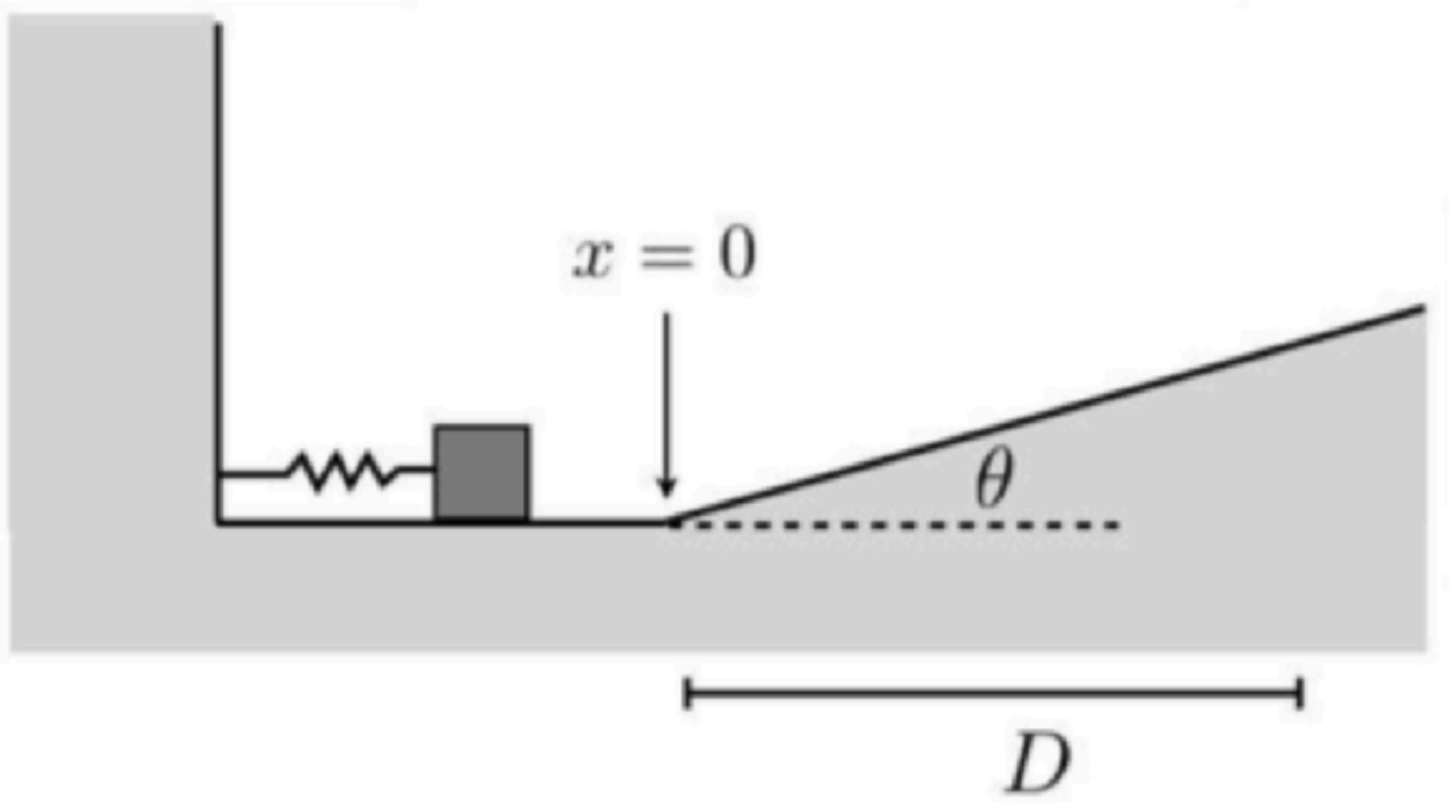
The mechanical energy E of a particle stays constant unless forces outside the system or non-conservative forces do work on it, in which case, the change in the mechanical energy is equal to the work done by the non-conservative forces:

$$W_{\text{nc},AB} = \Delta(K + U)_{AB} = \Delta E_{AB}. \tag{8.12}$$

Hints for HW 8.10

Spring on an Incline

A small 5 kg block is accelerated from rest on a flat surface by a compressed spring (k = 658 N/m) along a frictionless, horizontal surface. The block leaves the spring at the spring's equilibrium position (x = 0) and travels on an incline (θ = 25°) with a coefficient of kinetic friction μ_k = 0.25. The block moves a horizontal distance D = 8 m before coming to a stop.



Part 1

(a) What is the initial compression of the spring?

$x =$ number (rtol=0.02, atol=1e-08) m

Part 2

(b) What is the maximum kinetic energy of the block?

$K_{max} =$ number (rtol=0.05, atol=1e-08) 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 $\vec{\mathbf{r}}_0$	$\Delta U = U\left(\vec{\mathbf{r}}\right) - U\left(\vec{\mathbf{r}}_0\right)$
Gravitational potential energy near Earth's surface	$U\left(y\right) = mgy + \text{const.}$
Potential energy for an ideal spring	$U\left(x\right) = \frac{1}{2}kx^2 + \text{const.}$
Work done by conservative force over a closed path	$W_{\text{closed path}} = \int \vec{\mathbf{F}}_{\text{cons}} \cdot d\vec{\mathbf{r}} = 0$
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	$0 = W_{nc,AB} = \Delta(K + U)_{AB} = \Delta E_{AB}.$

Words of Advice

& What to do if you're really lost…

How to do well in this course

Tip

Full credit for the original version of this document below goes to Dr. Simon Bates from Physics 117 at UBC-Vancouver.

The material below has been used and adapted with his permission.

Introduction

Your success in this course depends to a large extent how you approach it, and how you engage with the activities, the materials and each other.
Here, we give you some ideas and advice on how to do well in the course that you might find useful as you embark on the course.
But before that, here are some key ideas about learning that we have used in designing this course activities and assessments:

Learning is a contact sport.

It's not like watching a good movie, where you can just let it wash over you.
You have to engage to really learn; you have to struggle to learn.
It's hard, it sometimes won't make sense and it takes time and persistence.
You might have found learning (and passing exams) pretty easy to this point; university might well be very different.

Memorizing is not learning.

We won't emphasize memorizing in this course. Every test you do, you can take in your own notes (we call these 'open note' tests).
So more important than remembering every single equation we will use, is knowing when to use which ones, how to use them to solve problems and evaluating if what you've calculated makes sense.

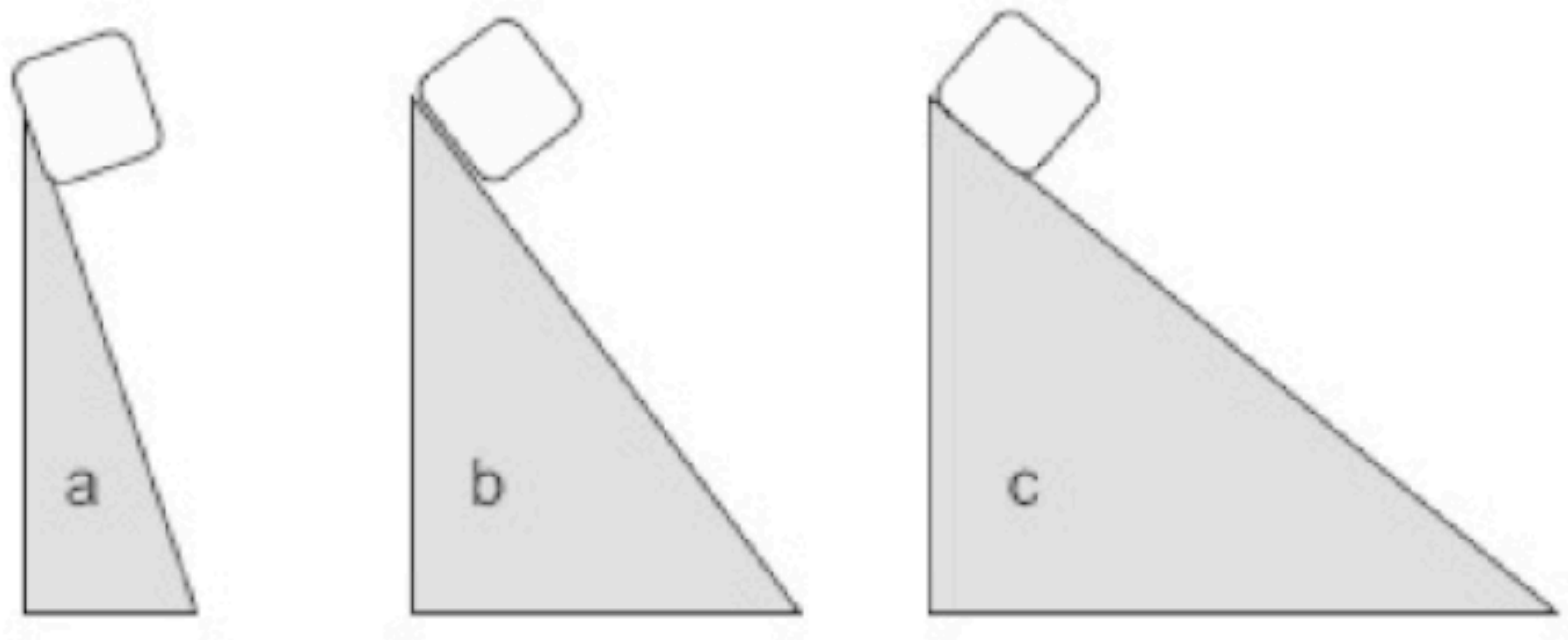
Understanding is learning and understanding should be your goal.

Can you explain an idea or a concept from this course to someone else in a way that they will understand it? And some time after you studied it?
This is the acid test for learning and it is one reason why we place such a lot of value on interaction and communication with your peers in this course.

Clicker Questions

CQ.9.4

Consider this figure. Three blocks of mass m slide down different inclined planes, each beginning at a height h. All of the planes are frictionless. Which block has the most energy at the bottom of the inclined plane?



a) a

b) b

c) c

d) All have the same energy.

A B C D E

CQ.9.4

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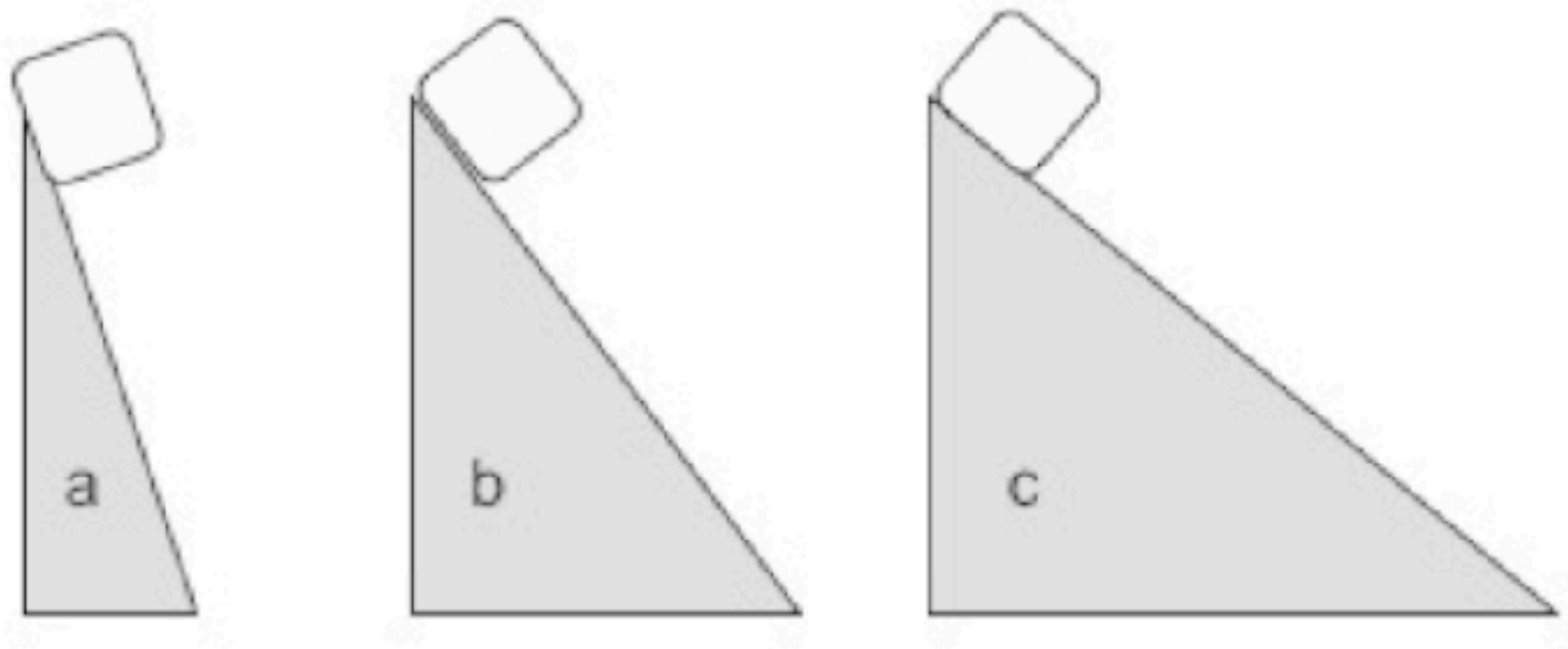

a) a

b) b

c) c

d) All have the same energy.

A B C D E

CQ.9.5

A boulder rolls from the top of a mountain, travels across a valley below, and rolls part way up the ridge on the opposite side. Describe all the energy transformations taking place during these events and identify when they happen.

a) As the boulder rolls down the mountainside, KE is converted to PE. As the boulder rolls up the opposite slope, PE is converted to KE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

b) As the boulder rolls down the mountainside, KE is converted to PE. As the boulder rolls up the opposite slope, KE is converted to PE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

c) As the boulder rolls down the mountainside, PE is converted to KE. As the boulder rolls up the opposite slope, PE is converted to KE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

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CQ.9.5

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a) As the boulder rolls down the mountainside, KE is converted to PE. As the boulder rolls up the opposite slope, PE is converted to KE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

Recall the correct definition for kinetic and potential energy. Energy associated with position is potential energy while energy associated with motion is kinetic energy.

b) As the boulder rolls down the mountainside, KE is converted to PE. As the boulder rolls up the opposite slope, KE is converted to PE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

It is correct that when the boulder rolls up the opposite side, KE is converted to PE. But when it rolls down the mountainside, the height is decreasing so PE cannot increase.

c) As the boulder rolls down the mountainside, PE is converted to KE. As the boulder rolls up the opposite slope, PE is converted to KE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

Yes, when the boulder rolls down the mountainside, PE is converted to KE. But when it rolls up the opposite side of the mountain the speed is decreasing and hence KE decreases.

d) As the boulder rolls down the mountainside, PE is converted to KE. As the boulder rolls up the opposite slope, KE is converted to PE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy due to friction.

This is the correct order of transformation of energy. Since there is friction, the mechanical energy will not be constant.

Detailed solution: As the boulder rolls down the mountainside, PE is converted to KE. As the boulder rolls up the opposite slope, KE is converted to PE. The boulder rolls only partway up the ridge because some of the PE has been converted to thermal energy by friction.

A B C D E

CQ.9.6

A marble rolling across a flat, hard surface at $2\,\mathrm{m/s}$ rolls up a ramp. Assuming that $g = 10\,\mathrm{m/s^2}$ and no energy is lost to friction, what will be the vertical height of the marble when it comes to a stop before rolling back down? Ignore effects due to the rotational kinetic energy.

a) $0.1\,\mathrm{m}$

b) $0.2\,\mathrm{m}$

c) $0.4\,\mathrm{m}$

d) $2\,\mathrm{m}$

A B C D E

CQ.9.6

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a) $0.1\,\mathrm{m}$

✔ b) $0.2\,\mathrm{m}$

c) $0.4\,\mathrm{m}$

d) $2\,\mathrm{m}$

Detailed solution:

$$mgh = \frac{mv^2}{2};\ h = \frac{2^2}{(2)(10)} = 0.2\,\mathrm{m}$$

A

B

C

D

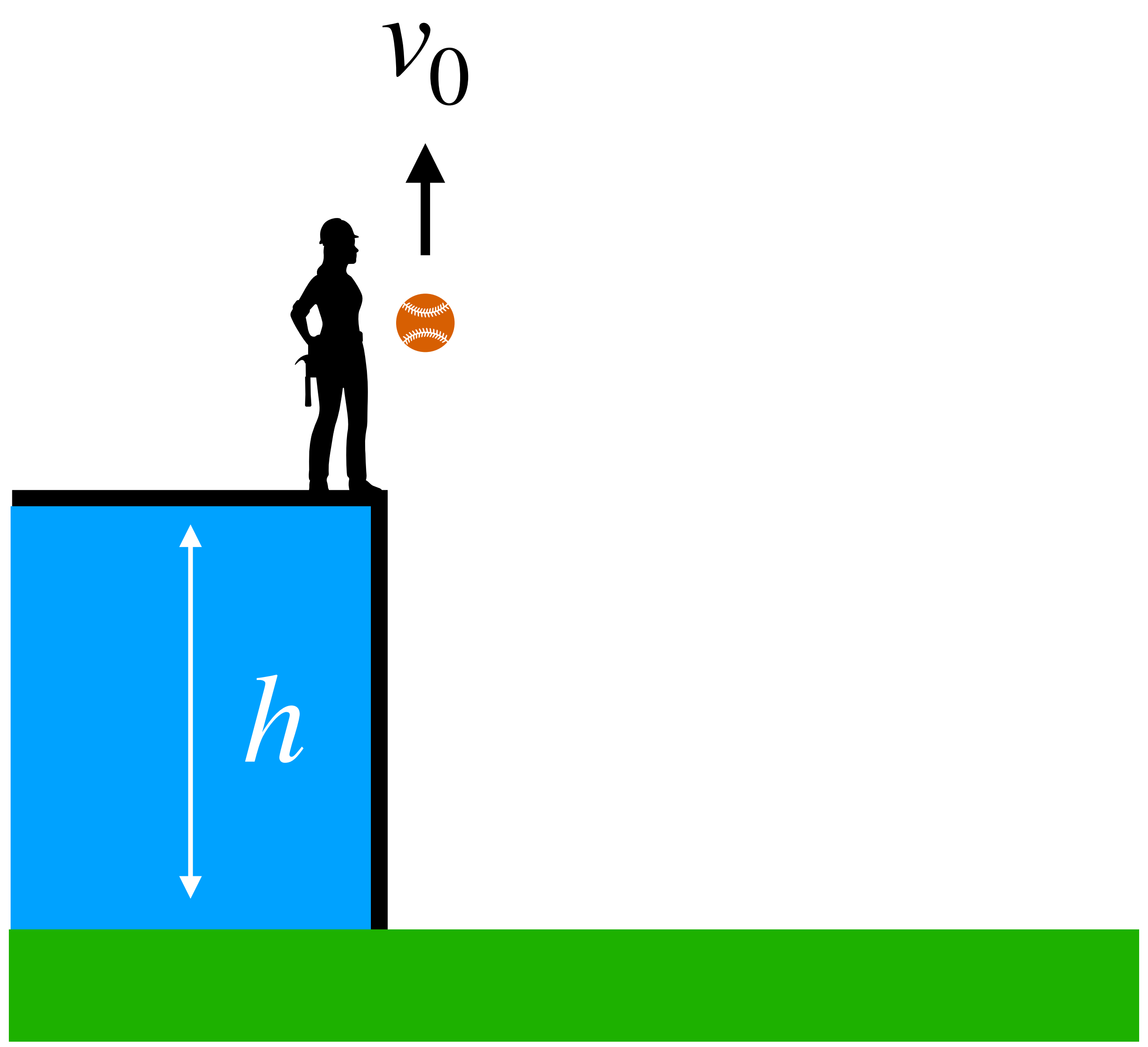
E

Activity:
Worked Problems

A person standing at the edge of a building of height h tosses a ball straight up with a velocity v_0, and lets it fall to the ground. Find a) the maximum height the ball reaches and b) the velocity of the ball just before it hits the ground. You may ignore air resistance.

WP 9.2

Solve the problem in two ways: using Kinematics, and then Energy.



One more thing…

Preview of what's left

Preview of what's left

Did we just violate Conservation of Energy?

Find out... after we come back from Reading Break!

See you next class!

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