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Physics 111 - Class 8B
Work & Kinetic Energy

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October 27, 2021

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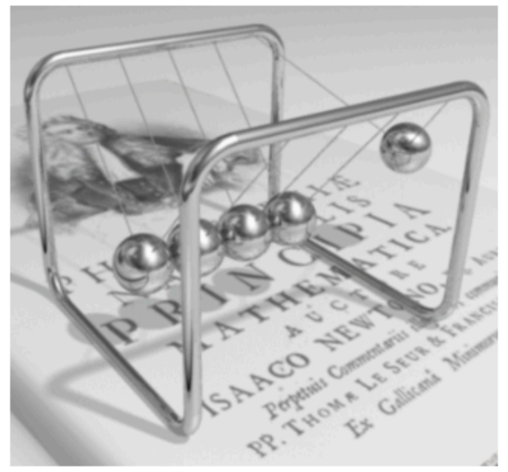
Class Outline

- Logistics / Announcements
- Mid-course Feedback Results
- Introduction to Chapter 7
- Clicker Questions
- Activity: Worked Problems

Logistics/Announcements

- Lab this week: Lab 5
- HW7 due this week on Thursday at 6 PM
- Learning Log 7 due on Saturday at 6 PM
- HW and LL deadlines have a 48 hour grace period
- Test/Bonus Test: Test 3 available this week (Chapters 5 & 6)
    - Test Window: Friday 6 PM - Sunday 6 PM



Physics 111

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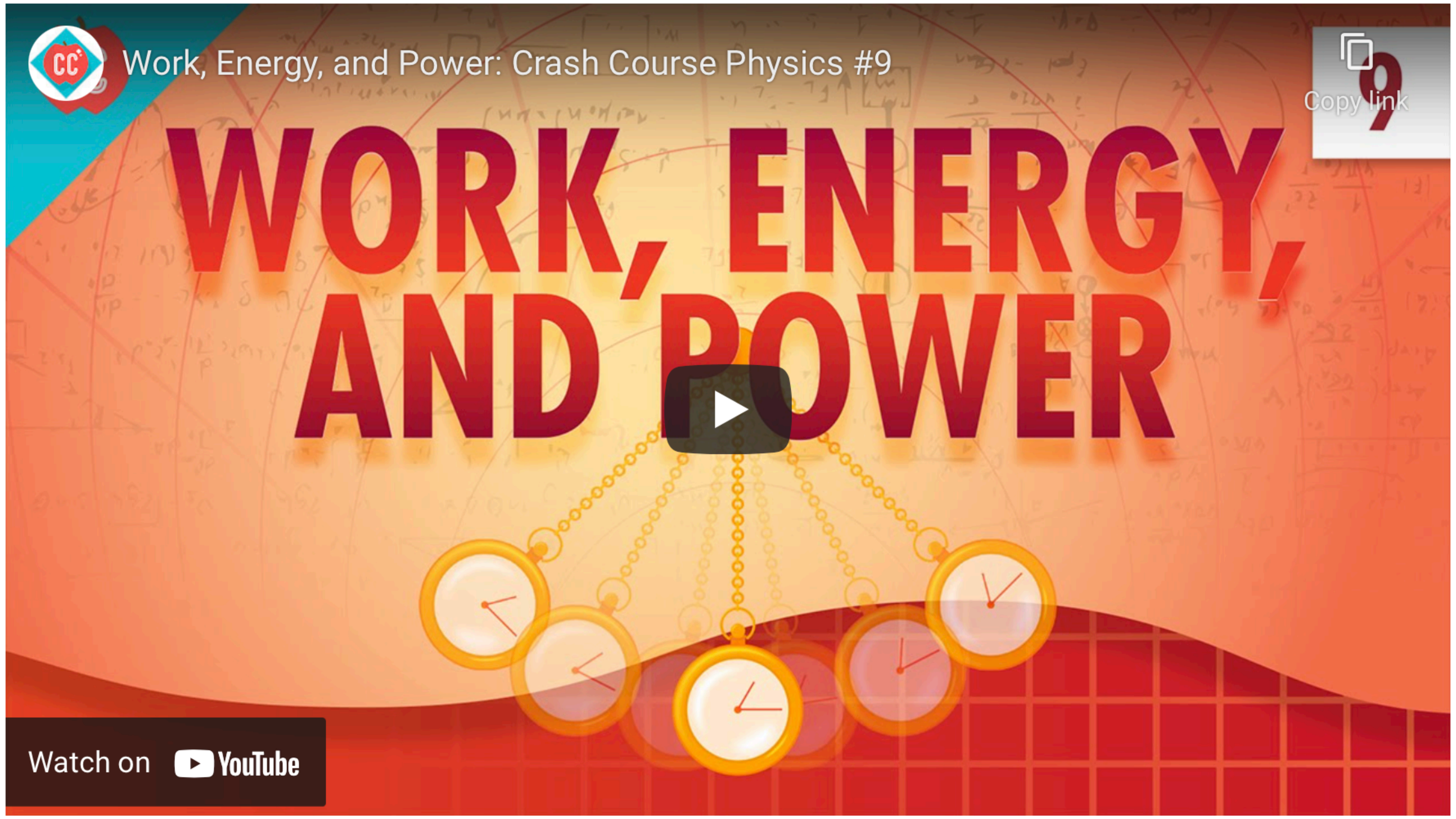
Work, Energy, and Power



Required Videos

1. Introduction to Work with Examples

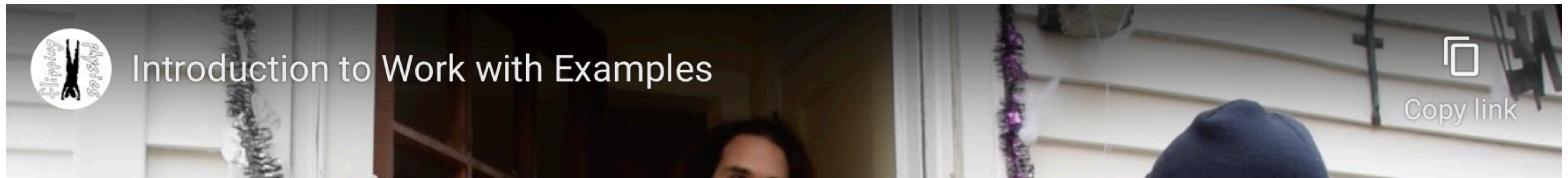


Figure 7.1 A sprinter exerts her maximum power with the greatest force in the short time her foot is in contact with the ground. This adds to her kinetic energy, preventing her from slowing down during the race. Pushing back hard on the track generates a reaction force that propels the sprinter forward to win at the finish. (credit: modification of work by Marie-Lan Nguyen)

Chapter Outline

In this chapter, we discuss some basic physical concepts involved in every physical motion in the universe, going beyond the concepts of force and change in motion, which we discussed in Motion in Two and Three Dimensions and Newton's Laws of Motion. These concepts are work, kinetic energy, and power. We explain how these quantities are

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My highlights

Figure 7.1 A sprinter exerts her maximum power with the greatest force in the short time her foot is in contact with the ground. This adds to her kinetic energy, preventing her from slowing down during the race. Pushing back hard on the track generates a reaction force that propels the sprinter forward to win at the finish. (credit: modification of work by Marie-Lan Nguyen)

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Energy

- In the first part of the course, we talked about the motion of objects and systems (Kinematics) and “tools of the trade” like trigonometry, derivatives, integrals, and vector decomposition.
- In the second part of the course, we talked about *how Forces affect the motion of objects and systems.*
- In the last part of the course, we will talk about Energy; which is a very helpful accounting tool to help us understand what happens when Forces are applied to other objects.

Wednesday's Class

7.2 Kinetic Energy
7.3 Work-Energy Theorem

Kinetic Energy

KINETIC ENERGY

The kinetic energy of a particle is one-half the product of the particle's mass *m* and the square of its speed *v*:

$$K = \frac{1}{2}mv^2. \tag{7.6}$$

- Kinetic Energy is a scalar
- Since the mass is always > 0, K is always $\geq$ 0
- Kinetic Energy is relative (to the reference frame)

EXAMPLE 7.7

Kinetic Energy Relative to Different Frames

A 75.0-kg person walks down the central aisle of a subway car at a speed of 1.50 m/s relative to the car, whereas the train is moving at 15.0 m/s relative to the tracks. (a) What is the person's kinetic energy relative to the car? (b) What is the person's kinetic energy relative to the tracks? (c) What is the person's kinetic energy relative to a frame moving with the person?

Strategy

Since speeds are given, we can use $\frac{1}{2}mv^2$ to calculate the person's kinetic energy. However, in part (a), the person's speed is relative to the subway car (as given); in part (b), it is relative to the tracks; and in part (c), it is zero. If we denote the car frame by C, the track frame by T, and the person by P, the relative velocities in part (b) are related by $\vec{\mathbf{v}}_{PT} = \vec{\mathbf{v}}_{PC} + \vec{\mathbf{v}}_{CT}$. We can assume that the central aisle and the tracks lie along the same line, but the direction the person is walking relative to the car isn't specified, so we will give an answer for each possibility, $v_{PT} = v_{CT} \pm v_{PC}$, as shown in Figure 7.10.

Figure 7.10 The possible motions of a person walking in a train are (a) toward the front of the car and (b) toward the back of the car.

Solution

a. $K = \frac{1}{2}(75.0\ \text{kg})(1.50\ \text{m/s})^2 = 84.4\ \text{J}$.

b. $v_{PT} = (15.0 \pm 1.50)\ \text{m/s}$. Therefore, the two possible values for kinetic energy relative to the car are

$$K = \frac{1}{2}(75.0\ \text{kg})(13.5\ \text{m/s})^2 = 6.83\ \text{kJ}$$

and

$$K = \frac{1}{2}(75.0\ \text{kg})(16.5\ \text{m/s})^2 = 10.2\ \text{kJ}.$$

c. In a frame where $v_P = 0$, $K = 0$ as well.

Significance

You can see that the kinetic energy of an object can have very different values, depending on the frame of reference. However, the kinetic energy of an object can never be negative, since it is the product of the mass and the square of the speed, both of which are always positive or zero.

Work-Energy Theorem

WORK-ENERGY THEOREM

The net work done on a particle equals the change in the particle's kinetic energy:

$$W_{\text{net}} = K_B - K_A. \tag{7.9}$$

Example 7.9

EXAMPLE 7.9

Loop-the-Loop

The frictionless track for a toy car includes a loop-the-loop of radius *R*. How high, measured from the bottom of the loop, must the car be placed to start from rest on the approaching section of track and go all the way around the loop?

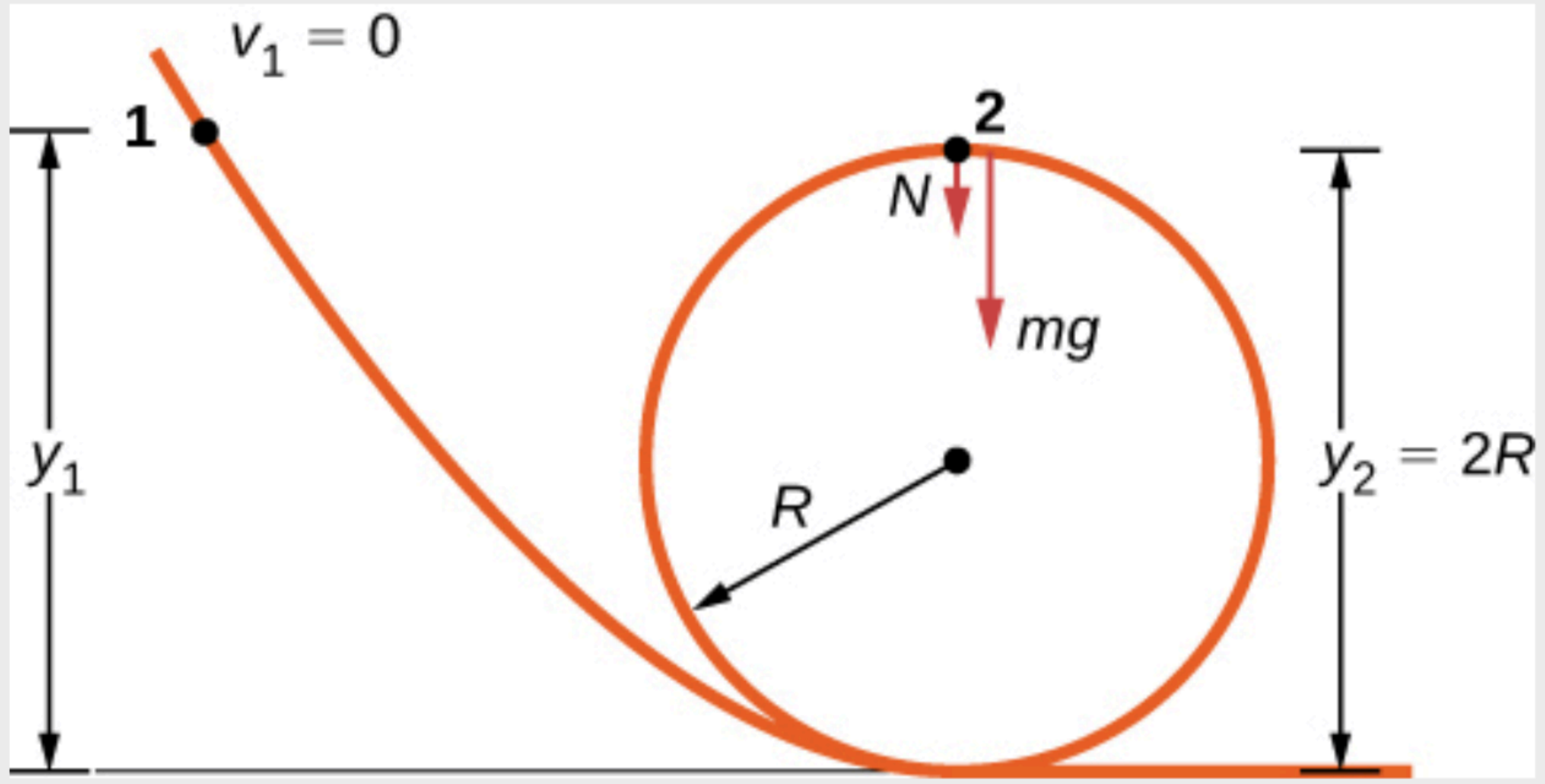

Figure 7.12 A frictionless track for a toy car has a loop-the-loop in it. How high must the car start so that it can go around the loop without falling off?

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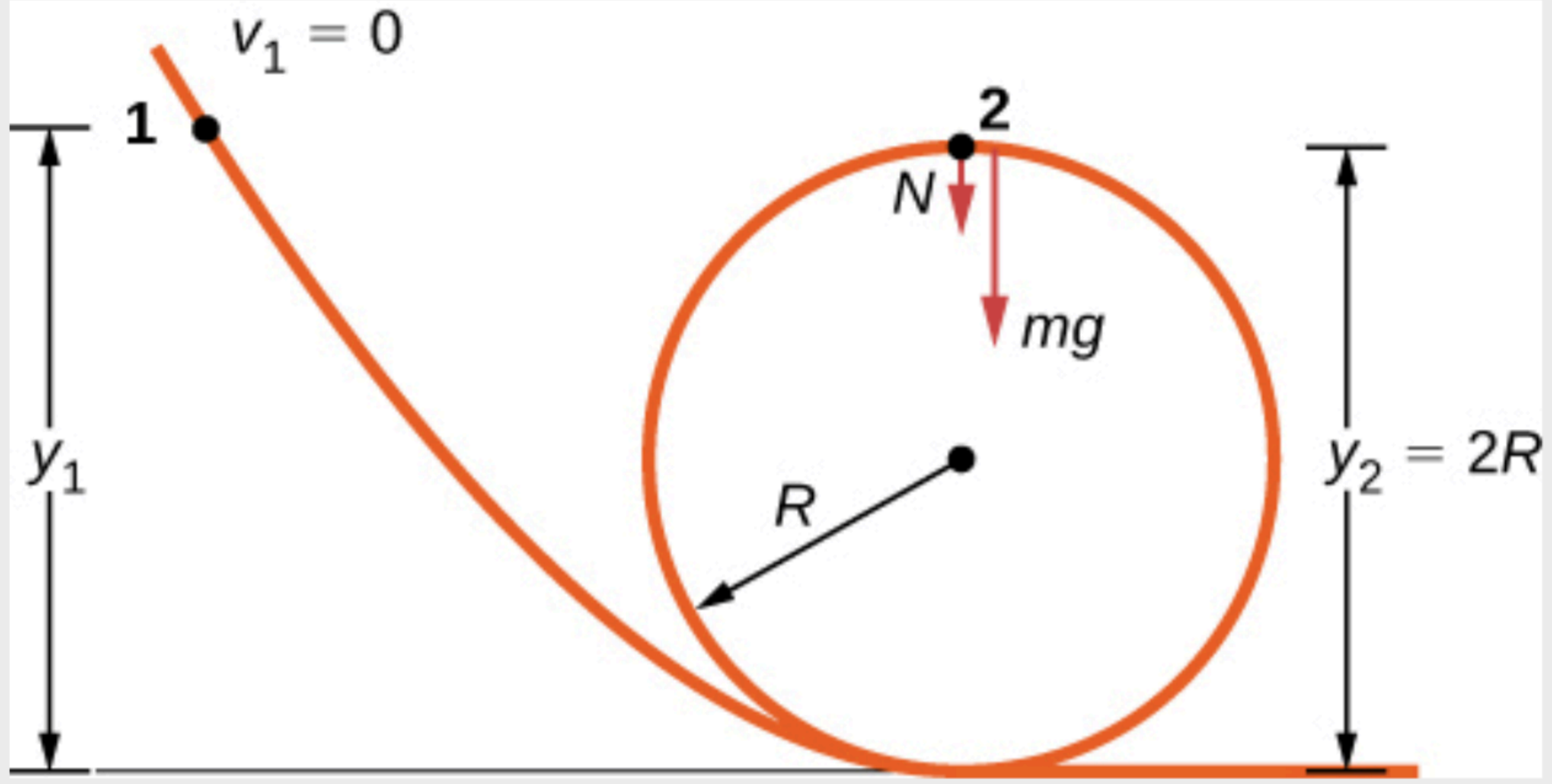

Figure 7.12 A frictionless track for a toy car has a loop-the-loop in it. How high must the car start so that it can go around the loop without falling off?

Solution

Implement the steps in the strategy to arrive at the desired result:

$$N = -mg + \frac{mv_2^2}{R} = \frac{-mgR + 2mg(y_1 - R)}{R} > 0 \quad \text{or} \quad y_1 > \frac{5R}{2}.$$

Significance

On the surface of the loop, the normal component of gravity and the normal contact force must provide the centripetal acceleration of the car going around the loop. The tangential component of gravity slows down or speeds up the car. A child would find out how high to start the car by trial and error, but now that you know the work-energy theorem, you can predict the minimum height (as well as other more useful results) from physical principles. By using the work-energy theorem, you did not have to solve a differential equation to determine the height.

Key Equations

Work done by a force over an infinitesimal displacement	$dW = \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}} = \left\lvert\vec{\mathbf{F}}\right\rvert \left\lvert d\vec{\mathbf{r}}\right\rvert \cos\theta$
Work done by a force acting along a path from *A* to *B*	$W_{AB} = \int_{\text{path}AB} \vec{\mathbf{F}} \cdot d\vec{\mathbf{r}}$
Work done by a constant force of kinetic friction	$W_{\text{fr}} = -f_k \lvert l_{AB}\rvert$
Work done going from *A* to *B* by Earth's gravity, near its surface	$W_{\text{grav},AB} = -mg\left(y_B - y_A\right)$
Work done going from *A* to *B* by one-dimensional spring force	$W_{\text{spring},AB} = -\left(\frac{1}{2}k\right)\left(x_B^2 - x_A^2\right)$
Kinetic energy of a non-relativistic particle	$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
Work-energy theorem	$W_{\text{net}} = K_B - K_A$
Power as rate of doing work	$P = \frac{dW}{dt}$
Power as the dot product of force and velocity	$P = \vec{\mathbf{F}} \cdot \vec{\mathbf{v}}$

Clicker Questions

CQ.8.5

True or False: To calculate the speed of the pebble dropped from the cliff as it hits the ground requires you to only know the height of the cliff and acceleration due to gravity, assuming air resistance or drag is negligible.

a) True

b) False

A

B

C

D

E

CQ.8.5

True or False: To calculate the speed of the pebble dropped from the cliff as it hits the ground requires you to only know the height of the cliff and acceleration due to gravity, assuming air resistance or drag is negligible.

✓ a) True

b) False

Detailed solution: Conservation of mechanical energy of the system gives $\frac{1}{2}mv^2 = mgh$. The mass m cancels, so $v = (2gh)^{1/2}$, and g and h are known.

A

B

C

D

E

CQ.8.6

What is the kinetic energy of $1,000\text{kg}$ car traveling at a velocity of $20\,\text{m/s}$?

a) 1×10^4 J

b) 2×10^4 J

c) 1×10^5 J

d) 2×10^5 J

A B C D E

CQ.8.6

What is the kinetic energy of $1,000\text{kg}$ car traveling at a velocity of $20\,\text{m/s}$?

a) 1×10^4 J

b) 2×10^4 J

c) 1×10^5 J

✓ d) 2×10^5 J

Detailed solution:

$$KE = \frac{mv^2}{2} = \frac{(1000)\,(20)^2}{2} = 2 \times 10^5 \text{ J}$$

A B C D E

CQ.8.7

An ice skater with a mass of $50\,\mathrm{kg}$ is gliding across the ice at a speed of $8\,\mathrm{m/s}$ when her friend comes up from behind and gives her a push, causing her speed to increase to $12\,\mathrm{m/s}$. How much work did the friend do on the skater?

a) $-2000\,\mathrm{J}$

b) $-100\,\mathrm{J}$

c) $100\,\mathrm{J}$

d) $2000\,\mathrm{J}$

A B C D E

CQ.8.7

An ice skater with a mass of $50\,\mathrm{kg}$ is gliding across the ice at a speed of $8\,\mathrm{m/s}$ when her friend comes up from behind and gives her a push, causing her speed to increase to $12\,\mathrm{m/s}$. How much work did the friend do on the skater?

a) $-2000\,\mathrm{J}$

b) $-100\,\mathrm{J}$

c) $100\,\mathrm{J}$

✔ d) $2000\,\mathrm{J}$

Detailed solution: Identify the variables: $m = 50\,\mathrm{kg}$, $v_2 = 12\,\mathrm{m/s}$, and $v_1 = 8\,\mathrm{m/s}$. Substitute: $W = \frac{1}{2}50\,(12^2 - 8^2) = 2,000\,\mathrm{J}$.

A B C D E

CQ.8.8

Using energy considerations, calculate the average force a 60.0-kg sprinter exerts backward on the track to accelerate from 2.00 to 8.00 m/s in a distance of 25.0 m, if he encounters a headwind that exerts an average force of 30.0 N against him.

a) 102 N

b) 42.0 N

c) 1,800 N

d) 174 N

A B C D E

CQ.8.8

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c) 1,800 N

d) 174 N

A

B

C

D

E

Activity:
Worked Problems

36 . How much work does the force $F(x) = (-2.0/x)\,\mathrm{N}$ do on a particle as it moves from $x = 2.0\,\mathrm{m}$ to $x = 5.0\,\mathrm{m}$?

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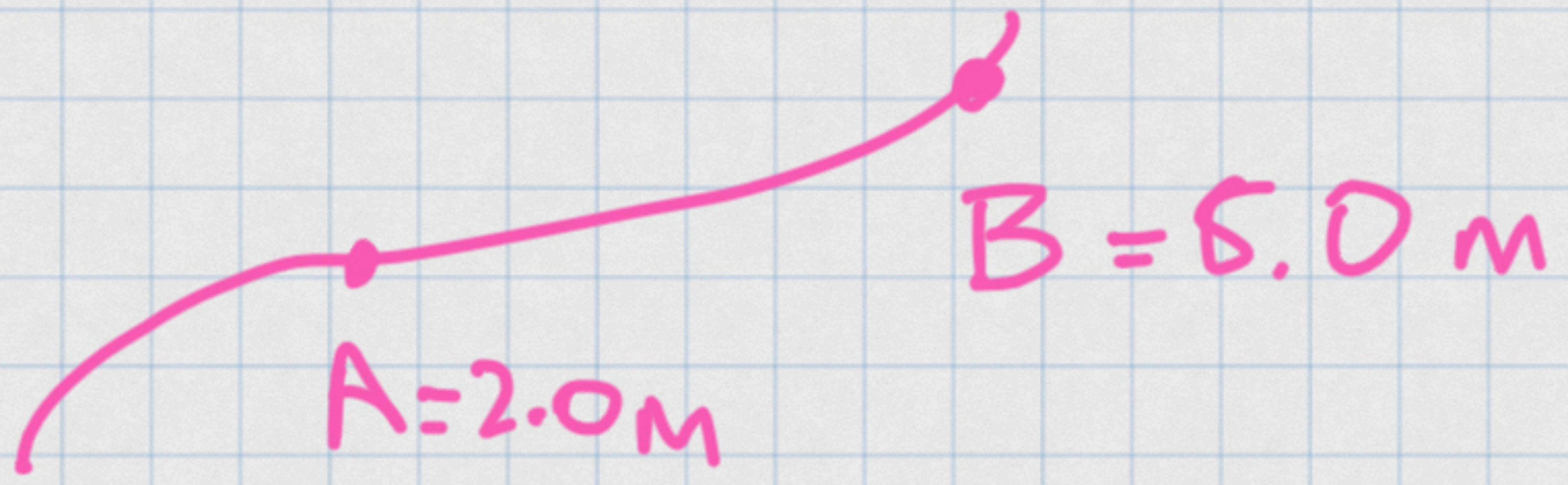


$$W = \int_A^B \vec{F} \cdot d\vec{r}$$

$$= \int_A^B \frac{-2}{x}\, d\vec{x} = -2\int_A^B \frac{1}{x}\, dx$$

$$= -2\,\left[\ln(x)\right]_A^B$$

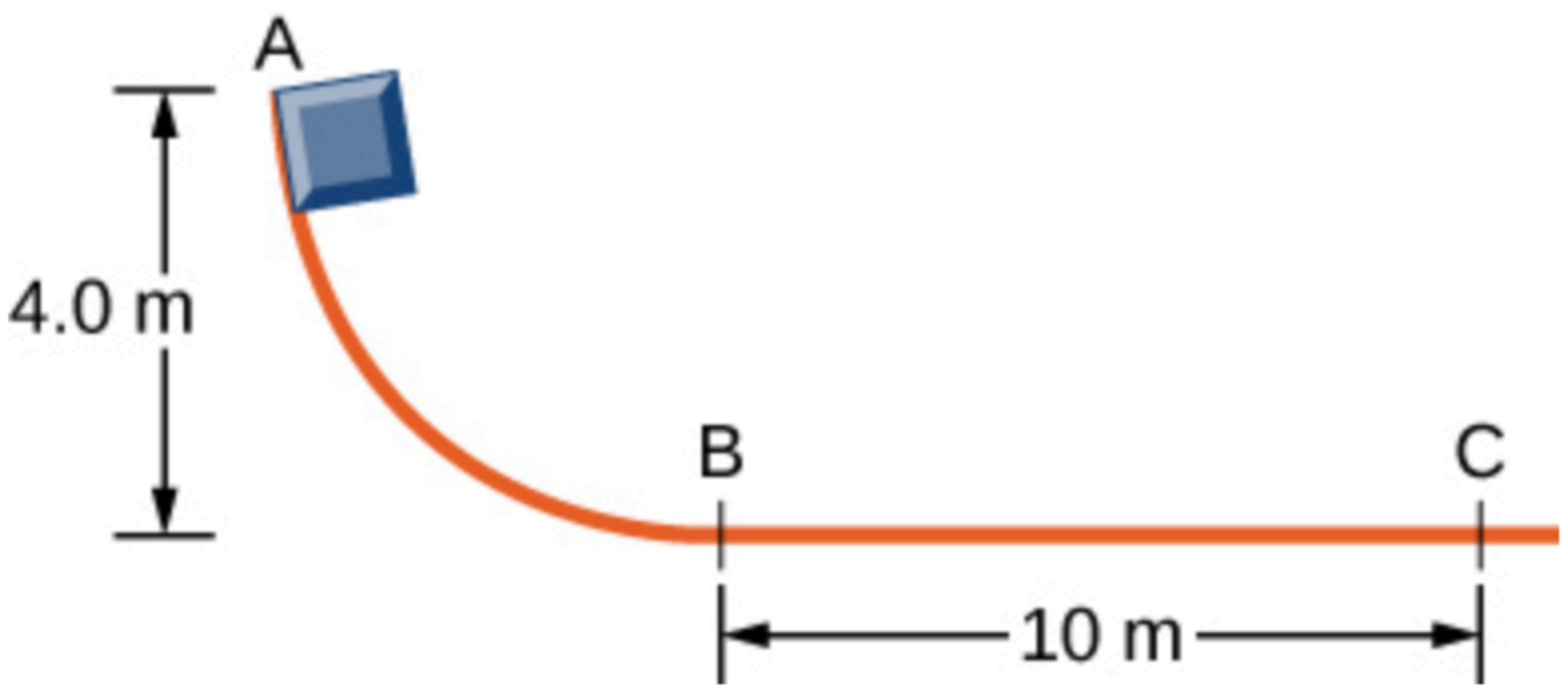
$$= -2\,\left[\ln 5 - \ln 2\right]$$

$$= -2\,\left[1.609 - 0.693\right]$$

$$\boxed{W = 1.83\ \text{J}}$$

62 . A small block of mass 200 g starts at rest at A, slides to B where its speed is $v_B = 8.0\ \mathrm{m/s}$, then slides along the horizontal surface a distance 10 m before coming to rest at C. (See below.) (a) What is the work of friction along the curved surface? (b) What is the coefficient of kinetic friction along the horizontal surface?

WP 7.3



Answers

a) -1.5 J

b) 0.4

WP 7.3

See you next class!

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