

# **Physics 111 - Class 8B**

# **Work & Kinetic Energy**

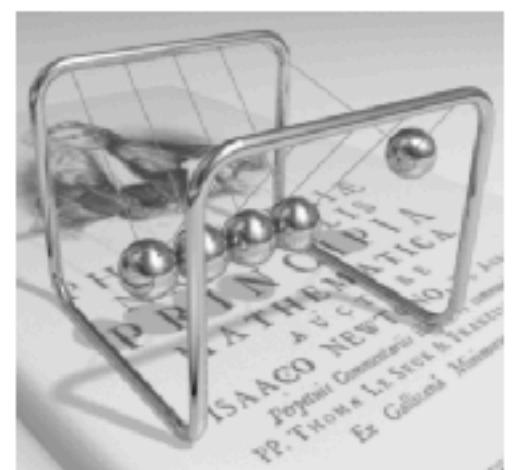
October 26, 2022

# Class Outline

- Logistics / Announcements
- 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 on Friday this week (Chapters 5 & 6)



## 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



## Work, Energy, and Power



Work, Energy, and Power: Crash Course Physics #9



# WORK, ENERGY, AND POWER



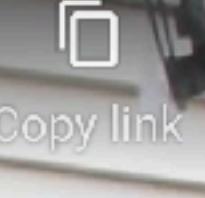
Watch on YouTube

## Required Videos

### 1. Introduction to Work with Examples



Introduction to Work with Examples



### VIDEO 1

- Video 2
- Video 3
- Video 4
- Video 5
- Video 6
- Video 7
- Video 8

Table of contents



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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

**Introduction**

- 7.1 Work
- 7.2 Kinetic Energy
- 7.3 Work-Energy Theorem
- 7.4 Power

▶ Chapter Review

- ▶ 8 Potential Energy and Conservation of Energy
- ▶ 9 Linear Momentum and Collisions
- ▶ 10 Fixed-Axis Rotation
- ▶ 11 Angular Momentum
- ▶ 12 Static Equilibrium and Elasticity
- ▶ 13 Gravitation
- ▶ 14 Fluid Mechanics



**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

- [7.1 Work](#)
- [7.2 Kinetic Energy](#)
- [7.3 Work-Energy Theorem](#)
- [7.4 Power](#)

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

# 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**

**7.3 Work-Energy Theorem**

**7.4 Power**

# Work-Energy Theorem

## WORK-ENERGY THEOREM

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

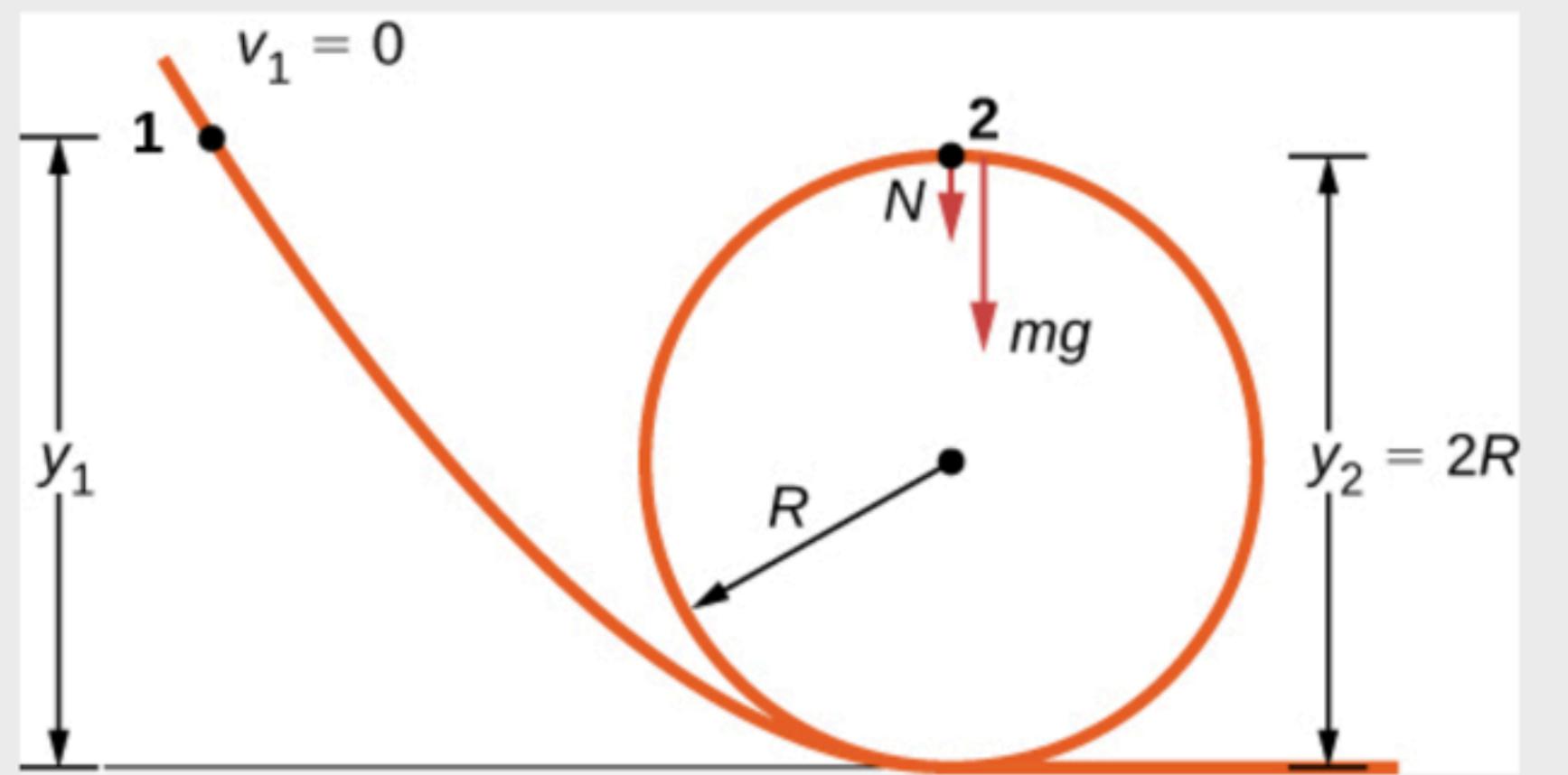
$$W_{\text{net}} = K_B - K_A.$$

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?

# Example 7.9

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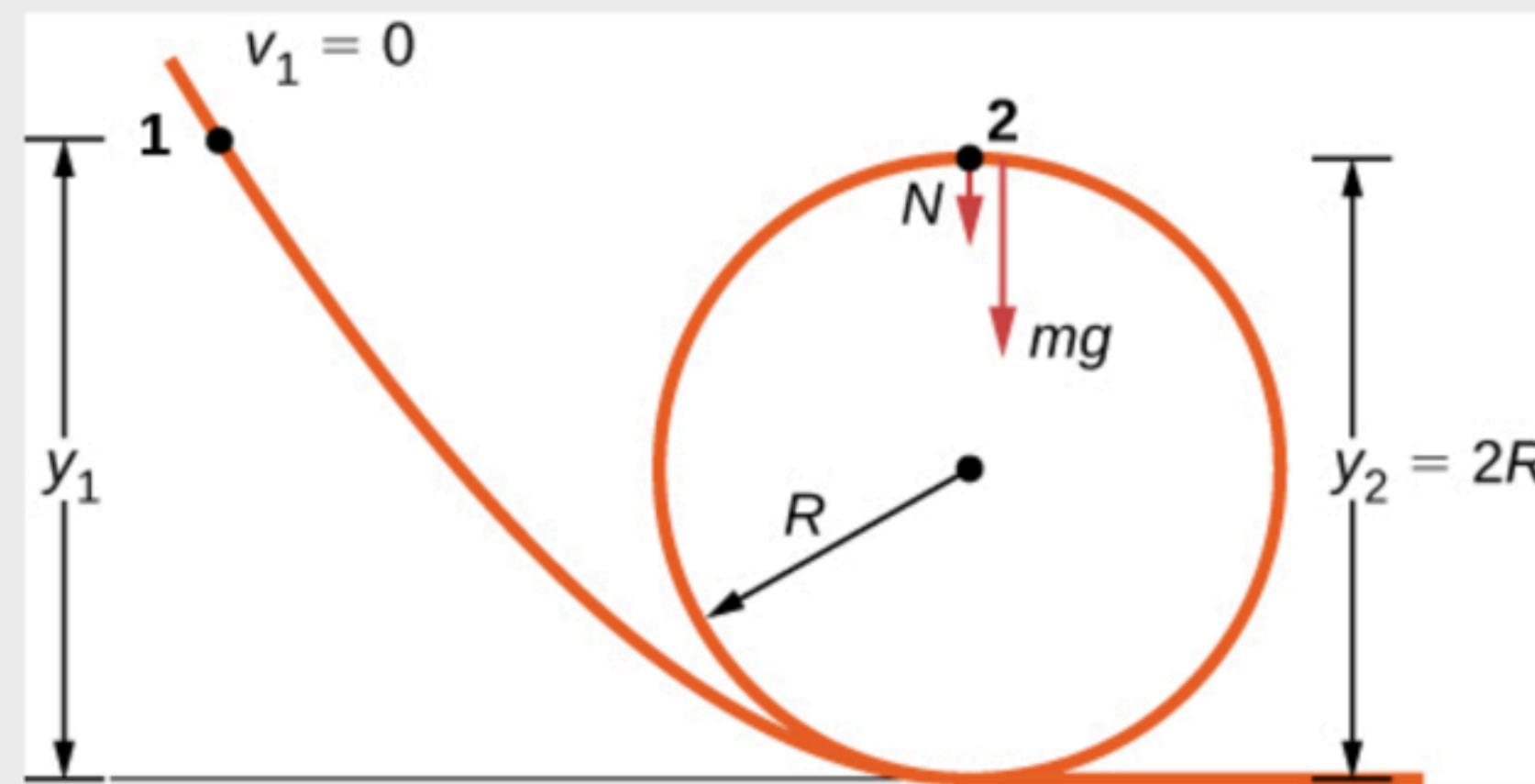


Figure 7.12 A frictionless track for a toy car has a loop-the-loop in it. How high must the car start so that it can go around the loop without falling off?

# Example 7.9

#### Solution

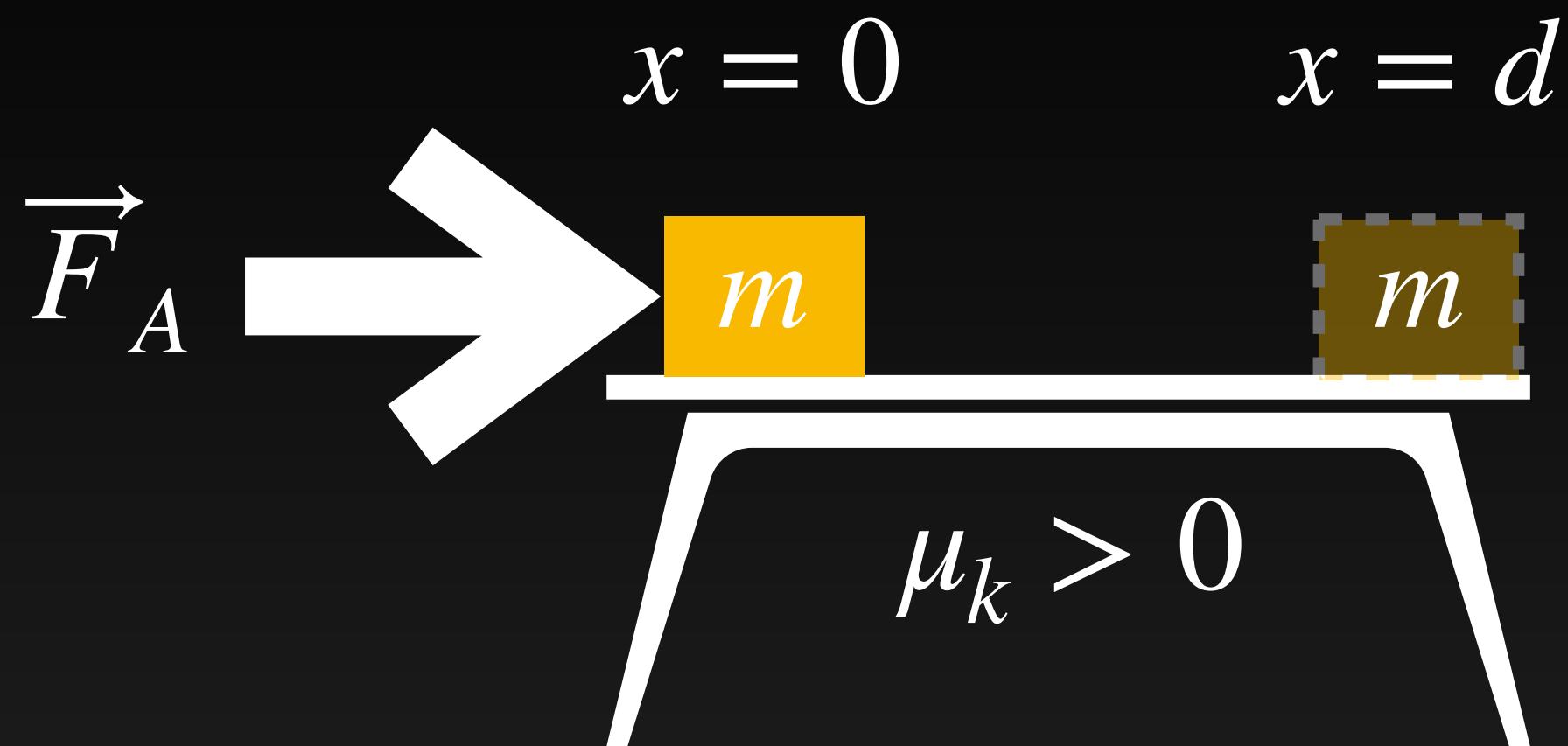
Implement the steps in the strategy to arrive at the desired result:

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

#### Significance

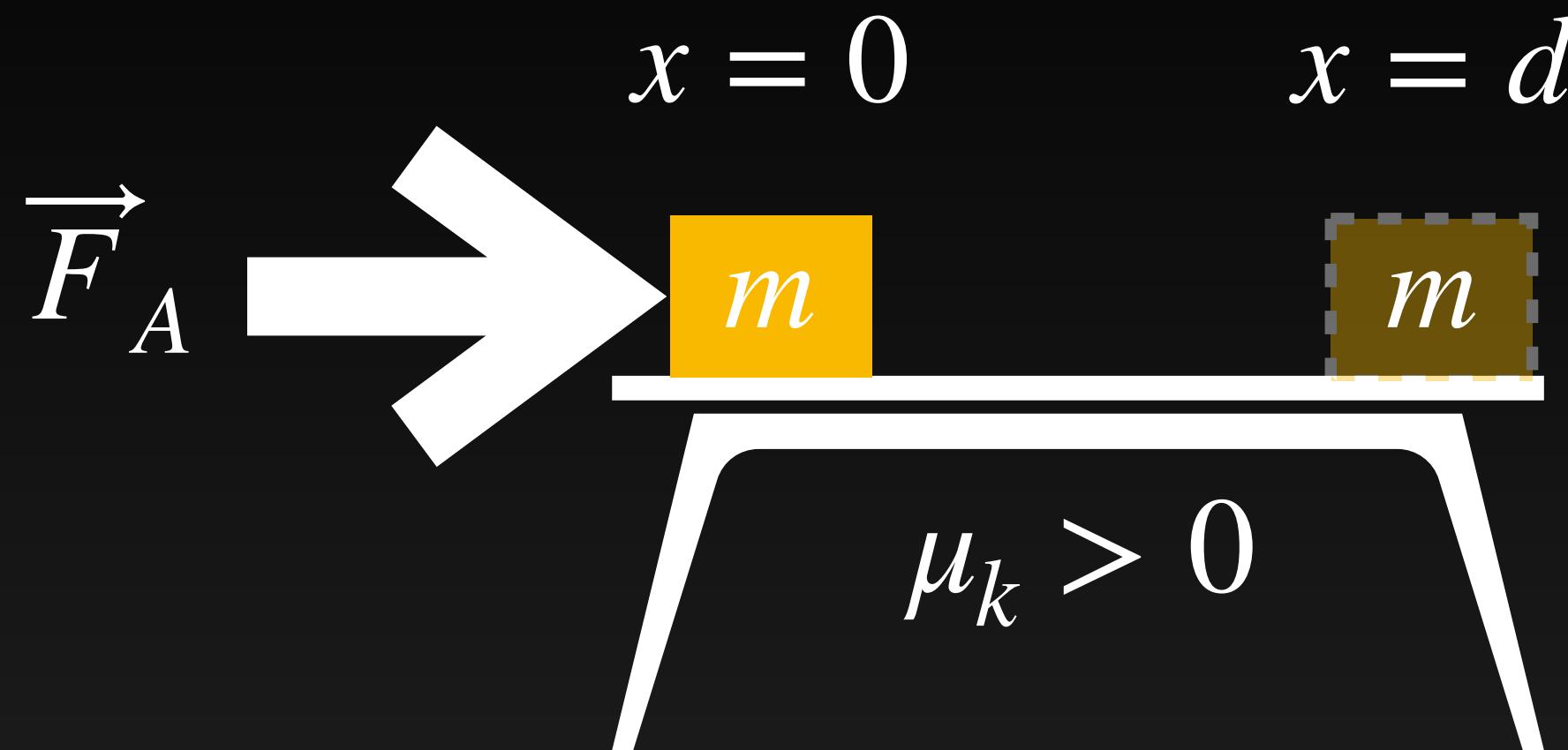
On the surface of the loop, the normal component of gravity and the normal contact force must provide the centripetal acceleration of the car going around the loop. The tangential component of gravity slows down or speeds up the car. A child would find out how high to start the car by trial and error, 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.

# Deriving the Work-Energy Theorem



A package of mass **m** on a table is being pushed to the right, starting at **x=0** and ending up at **x=d**. Analyze the situation and calculate the work done.

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## WORK-ENERGY THEOREM

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

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

7.9

# Power

Then, we can define the **instantaneous power** (frequently referred to as just plain **power**).

## POWER

Power is defined as the rate of doing work, or the limit of the average power for time intervals approaching zero,

$$P = \frac{dW}{dt}.$$

7.11

If the power is constant over a time interval, the average power for that interval equals the instantaneous power, and the work done by the agent supplying the power is  $W = P\Delta t$ . If the power during an interval varies with time, then the work done is the time integral of the power,

$$W = \int P dt.$$

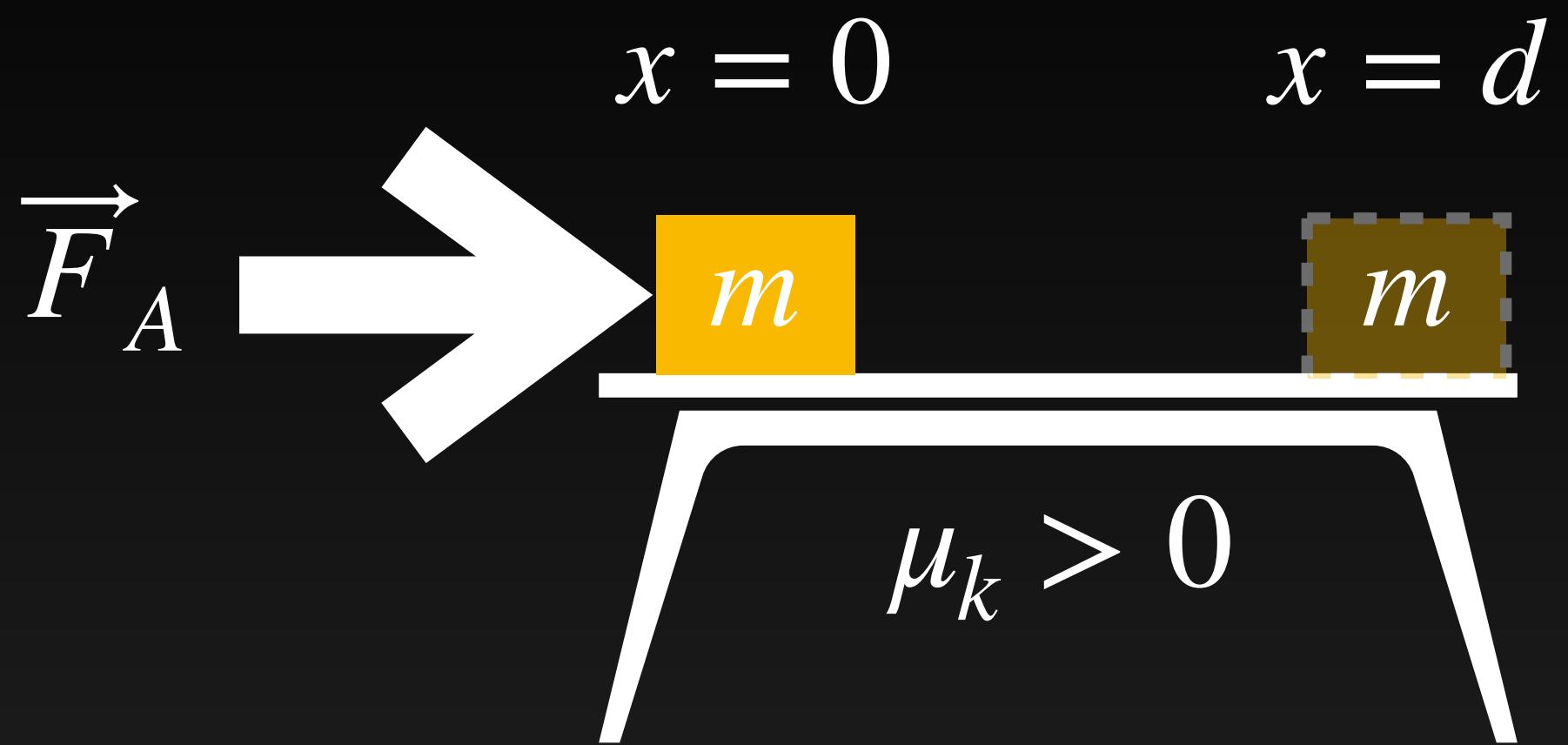
# Average Power

We express the relation between work done and the time interval involved in doing it, by introducing the concept of power. Since work can vary as a function of time, we first define **average power** as the work done during a time interval, divided by the interval,

$$P_{\text{ave}} = \frac{\Delta W}{\Delta t}.$$

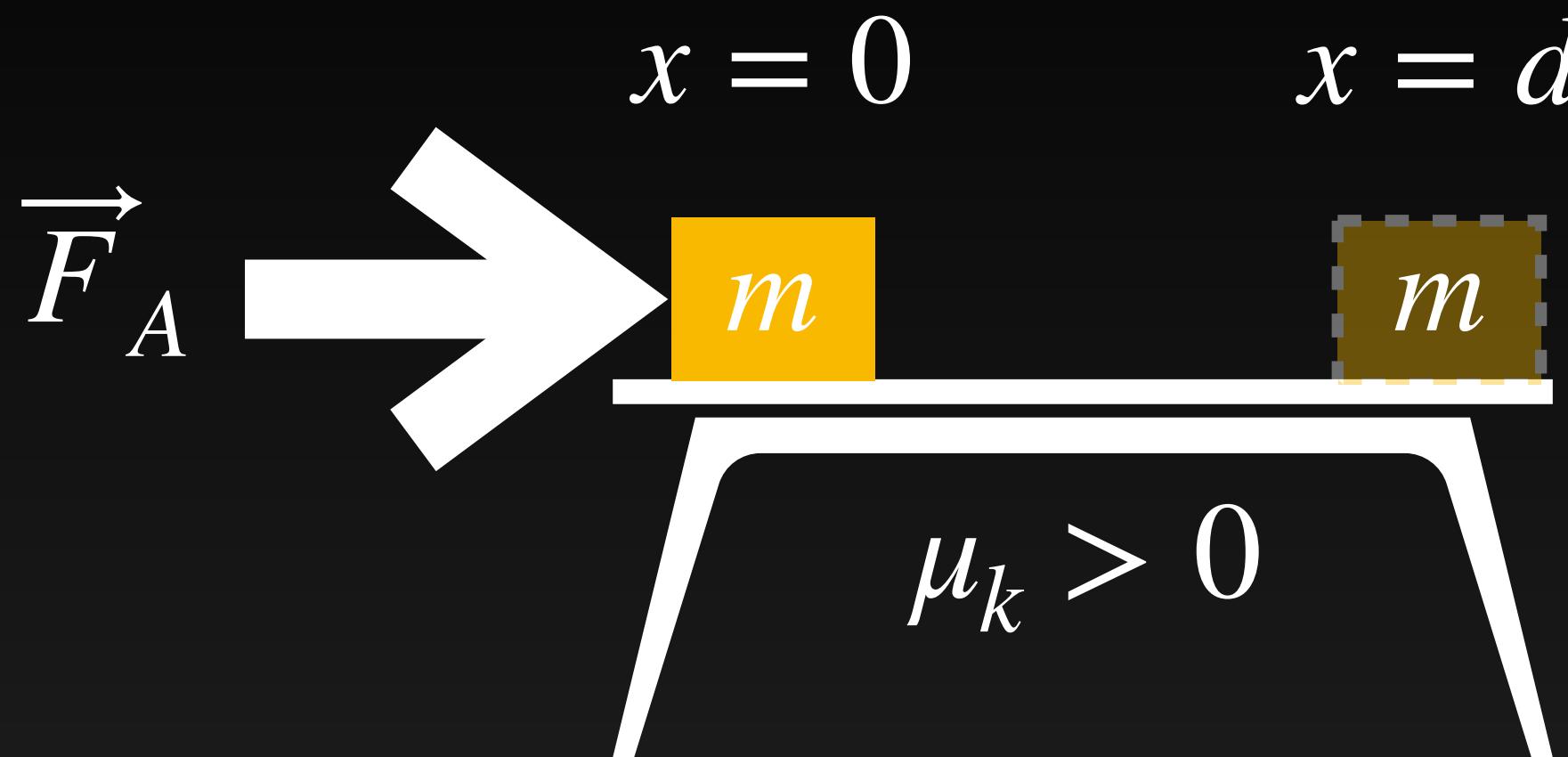
7.10

# Power required to move an object



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# Power required to move an object



A package of mass **m** on a table is being pushed to the right, starting at **x=0** and ending up at **x=d**. Analyze the situation and calculate the work done.

The power involved in moving a body can also be expressed in terms of the forces acting on it. If a force  $\vec{F}$  acts on a body that is displaced  $d\vec{r}$  in a time  $dt$ , the power expended by the force is

$$P = \frac{dW}{dt} = \frac{\vec{F} \cdot d\vec{r}}{dt} = \vec{F} \cdot \left( \frac{d\vec{r}}{dt} \right) = \vec{F} \cdot \vec{v}, \quad 7.12$$

where  $\vec{v}$  is the velocity of the body. The fact that the limits implied by the derivatives exist, for the motion of a real body, justifies the rearrangement of the infinitesimals.

A 90kg sprinter accelerates uniformly from rest to reach their maximum speed of 11m/s in 2 seconds.

What is their power output when their speed is 8m/s?

$$P = \text{number (rtol=0.05, atol=1e-08)}$$

W



# Key Equations

Work done by a force over an infinitesimal displacement

$$dW = \vec{F} \cdot d\vec{r} = |\vec{F}| |d\vec{r}| \cos \theta$$

Work done by a force acting along a path from  $A$  to  $B$

$$W_{AB} = \int_{\text{path } AB} \vec{F} \cdot d\vec{r}$$

Work done by a constant force of kinetic friction

$$W_{\text{fr}} = -f_k |l_{AB}|$$

Work done going from  $A$  to  $B$  by Earth's gravity, near its surface

$$W_{\text{grav},AB} = -mg (y_B - y_A)$$

Work done going from  $A$  to  $B$  by one-dimensional spring force

$$W_{\text{spring},AB} = -\left(\frac{1}{2}k\right)(x_B^2 - x_A^2)$$

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

$$P = \vec{F} \cdot \vec{v}$$

# 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.8.6

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

a)  $1 \times 10^4$  J

b)  $2 \times 10^4$  J

c)  $1 \times 10^5$  J

d)  $2 \times 10^5$  J

A

B

C

D

E

# CQ.8.7

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

- a) -2000 J
- b) -100 J
- c) 100 J
- d) 2000 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.8.9

A boy pushes his little sister on a sled. The sled accelerates from 0 to 3.2 m/s. If the combined mass of his sister and the sled is 40.0 kg and 18 W of power were generated, how long did the boy push the sled?

- a) 205 s
- b) 128, s
- c) 23 s
- d) 11 s

A

B

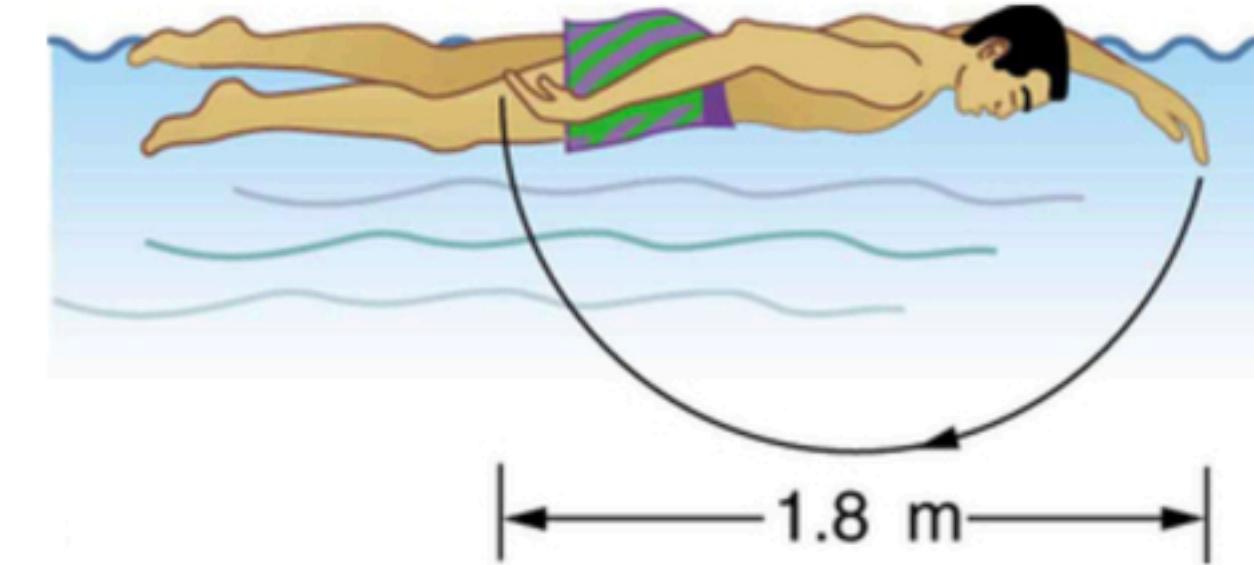
C

D

E

# CQ.8.10

The swimmer shown in the figure exerts an average horizontal backward force of 80.0 N with his arm during each 1.80 m long stroke.



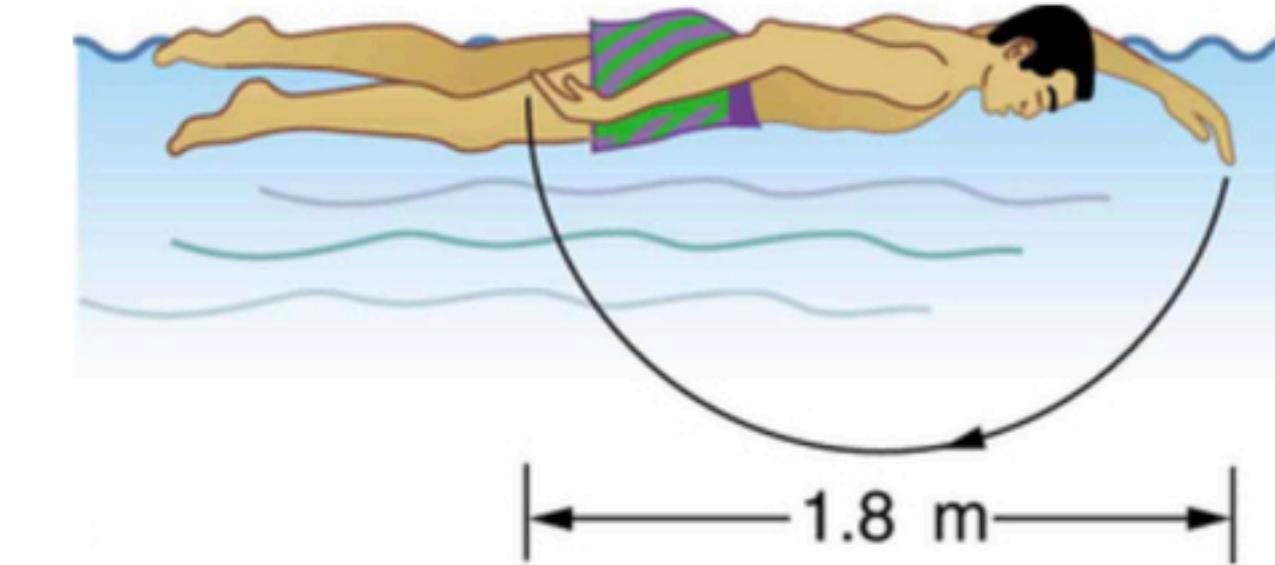
What is his work output in each stroke?

- a) 144 J
- b) 0.0 J
- c) 44.4 J
- d) 81.8 J

A      B      C      D      E

# CQ.8.11

The swimmer shown in the figure exerts an average horizontal backward force of 80.0 N with his arm during each 1.80 m long stroke.



What is his work output in each stroke?

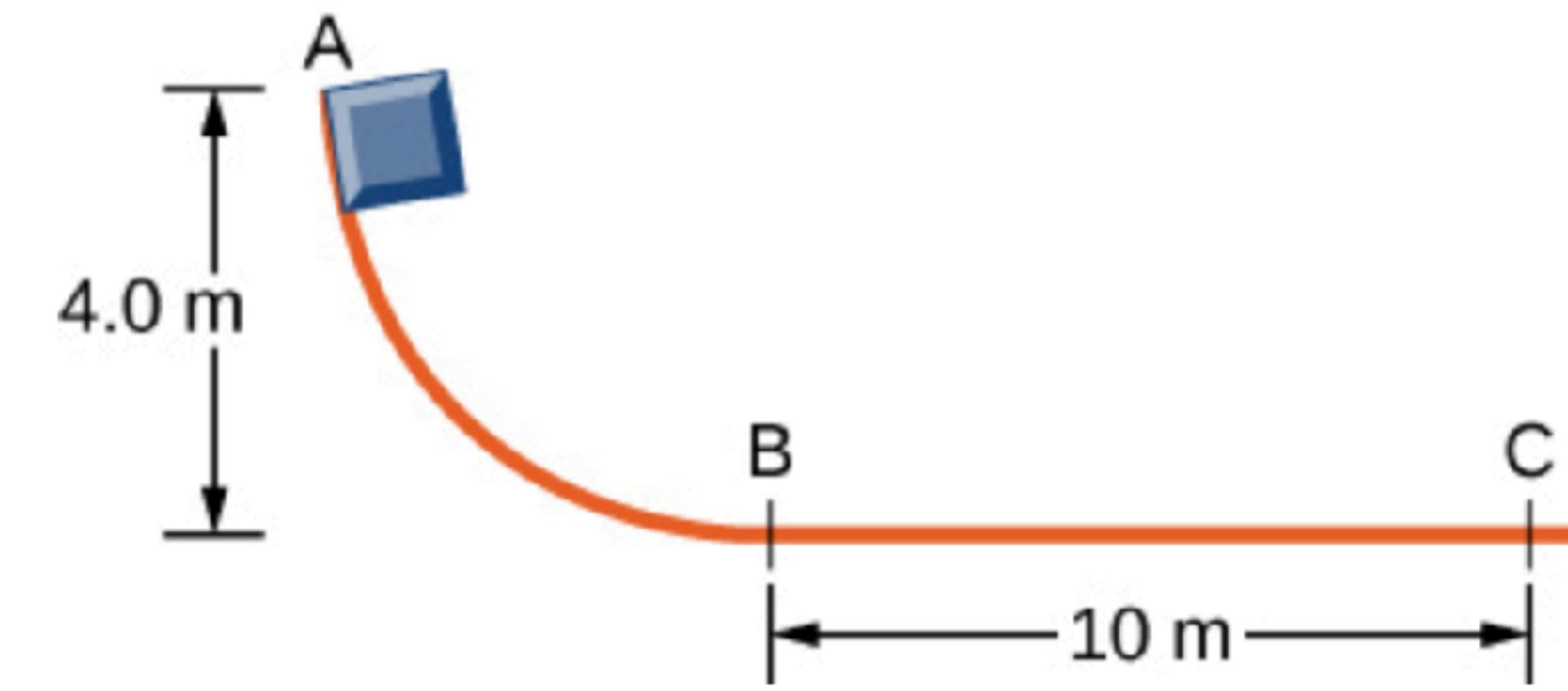
Calculate the power output of his arms if he does 120 strokes per minute.

- a) 288 W
- b) 17,300 W
- c) 2.40 W
- d) 4.80 W

A      B      C      D      E

# Activity: Worked Problems

62 . A small block of mass 200 g starts at rest at A, slides to B where its speed is  $v_B = 8.0 \text{ m/s}$ , 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?



88 . Consider a particle on which a force acts that depends on the position of the particle. This force is given by  $\vec{F}_1 = (2y)\hat{i} + (3x)\hat{j}$ . Find the work done by this force when the particle moves from the origin to a point 5 meters to the right on the x-axis.

WP 7.4

**88.** Consider a particle on which a force acts that depends on the position of the particle. This force is given by  $\vec{F}_1 = (2y)\hat{i} + (3x)\hat{j}$ . Find the work done by this force when the particle moves from the origin to a point 5 meters UP (+) on the y-axis.

**Extra**

**See you next class!**

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