

Introduction

Physics 211
Syracuse University, Physics 211 Spring 2016
Walter Freeman

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Physics 211

Forces and Motion



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Course webpage:

<http://walterfreeman.github.io/phy211/>

Overview of today

- Introduction to physics and mechanics
- Course organization / syllabus
- How to succeed in this course
- Describing the physical world: the SI system
- Mathematics in the context of physics

So what is this class?

Physics: what are the fundamental laws of nature?



These phenomena are all governed by the *same few principles*.

The most fundamental question physics asks:

“Why do things move in the ways that they do?”

The answer is given by Isaac Newton's second law of motion:

“Objects accelerate when pushed by forces; they accelerate in the direction of the force, proportional to the size of the force divided by their mass.”

That's it. We will spend much of our class talking about the meaning and consequences of this one statement.

The physicist's eye

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- “What phenomena are involved in this thing?”
- “How do they interact to determine its behavior?”

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In this class, you'll learn about some of those simple pieces, but that's not the important thing.

You'll also learn the skill of asking those two questions, and develop [a physicist's perspective for solving problems](#).

This will serve you well in whatever field you pursue, since the ability to quickly look at a problem and understand the crucial elements is universally helpful.

What is this (and how does it work)?



How it works: the physicist's perspective

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- They exert forces on each other through gravity

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- Too many stars to do with pen and paper...
- ... but a computer can do it! (youtube link)

Course structure and syllabus review

Four broad sections:

① Kinematics (understanding the right hand side of $\vec{F} = m\vec{a}$)

- How do we describe motion?
- How do an object's position, velocity, and acceleration relate?
- **What about rotational motion?**
- How do we deal with things in two or three dimensions?

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② Forces and motion (both sides of $\vec{F} = m\vec{a}$)

- What kinds of forces are there?
- **Torque: a rotational counterpart to force, with an equivalent to $\vec{F} = m\vec{a}$**
- Understanding different physical situations using $\vec{F} = m\vec{a}$
- Collisions and momentum: taking the integral of $\vec{F} = m\vec{a}$

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③ Two more mechanics topics

- Energy: a way to simplify solving $\vec{F} = m\vec{a}$ when you don't care about time
- **How do forces cause torques?**

④ An introduction to waves and acoustics

- What properties do waves traveling in space have?
- What happens to waves when they are trapped?
- **What are the physics of music and musical instruments?**
- **How does this relate to chemistry, biology, and engineering?**

Clickers

You all should have gotten a clicker from the bookstore.

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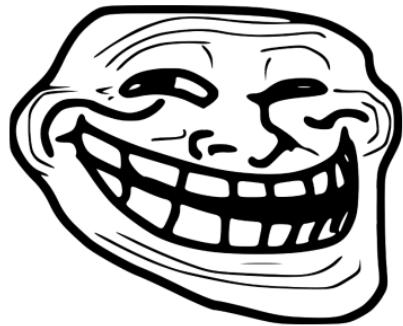
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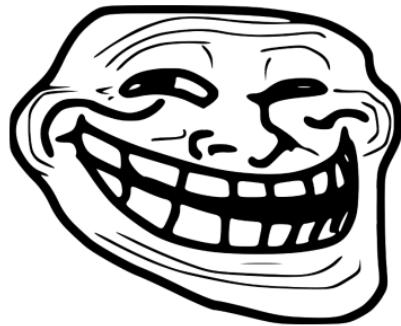


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We're using an extremely high-tech, state-of-the-art clicker system in this class. Make sure you get one, and bring it to class every day.

Mastering Physics is an online homework system.

Due to negative feedback from students I don't require it. Some options for buying the textbook online or in the bookstore may come with a code for it, but you do not need to buy it.

Mastering Physics is ~~an online homework system~~ a dumpster fire.

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Syllabus review

- Philosophy
- Grading
- The components of the course
- Academic integrity
- Students with disabilities, religious observance policy, and my attitude about these

Recitations

- Discussion sections led by your TA
- Homework is submitted and returned in recitation
- **Crucial** for your success in this class

In recitation, you can:

- Ask general questions to your TA and your peers
- You will be assigned groups, which will change after every exam
- Ask questions about the homework, or work on it in your groups

Remember:

- Physics is not about how much you know – it's about **what you can do**
- This class isn't about amassing facts; it's about solving problems
- This takes practice, and the recitations (and the homework) are where you get it
- The TA's this year are an amazing group; make use of them!

The course webpage and Facebook page

- All notes, etc., will be posted on the course website (not Blackboard)
 - I will also post course announcements there
 - The syllabus is posted there
 - You really should read the section on the course philosophy
-
- There is also a course Facebook page at
<https://www.facebook.com/groups/234894186963170/>
 - ... or search “Syracuse University Physics 211, Spring 2017”
 - Joining the group doesn’t mean anyone else can see your private posts, etc., or that you can see theirs
 - This is a great place to ask questions, get advice, and collaborate with your classmates
 - Up to 2% extra credit for those who help their peers

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These things are skills, and they all require practice
... but they also require you to ask questions and ask for guidance!

How to do well in this class: ask for guidance!

Some students might come to class, write down everything, go home and review, and then spend hours alone working on the homework.

They're diligent, good, hardworking students, right?

How to do well in this class: ask for guidance!

Some students might come to class, write down everything, go home and review, and then spend hours alone working on the homework.

They're diligent, good, hardworking students, right?

... but this is not the best way to learn skills! Instead, I hope you will:

- Interrupt me in class and ask questions
- Ask me questions by email to **wafreema@syr.edu**
 - I am often by a computer and you will often get a quick reply
 - You can take cellphone pictures of work and email them to me, too
- Ask questions on the Facebook group
- Come work with me and with your peers in my office hours
- Do your homework in the Physics Clinic when you can

Metaphors: sports and music

Learning physics is like learning to play a musical instrument.

The hard part isn't learning the notes – it's being able to play them, and tell a story with them.

How does studying the piano work?

- Your teacher shows you a few techniques, and gives you a piece to learn to play
- You take it home, practice it, and get stuck on difficult parts
- You ask your teacher for advice; she guides you
- You practice some more
- You repeat the previous steps until you've mastered the technique and the music

Learning a sport works the same way.

Physics is like this. We don't expect you to master everything immediately; physics takes practice, and it's okay to get stuck and ask questions. In fact, it's what I expect!

The Physics Clinic

The Clinic is in room 112; it's a large room with tables, boards, and (usually) a graduate teaching assistant. Often I and my coaches are there, too.

You can go there whenever the building is open to work in groups on your homework, and ask each other and the GTA for help.

I also hold my office hours there (although that might change soon).

This is an excellent resource for you to use; why do your homework alone when you can work with your peers and instructors?

Office hours

In the Physics Clinic (for now):

- Tuesdays: 5:10-6:50 PM
- Fridays: 9:30-11:30 AM
- Other times announced (if homework is due Friday, I may hold Thursday office hours)

or by appointment.

Outside these times you might find me in the Clinic or in my office in room 215.

Things in nature aren't just described by numbers; they have an associated *dimension*, and we measure them using a *system of units*.

We have three different kinds of dimension:

- **Length:** usually measured in **meters**; also inches, miles, light-years...
- **Mass:** usually measured in **kilograms**; also grams, tonnes...
- **Time:** usually measured in **seconds**; also hours, days...

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For the Americans: the pound measures *force*, not mass. The word “weight” means “force due to gravity”; an object with a mass of one kilogram weighs 2.2 pounds on Earth.

Math, physics-style, I: working with dimensions

“It is two hours from Syracuse to Adirondack State Park”

Does this statement make sense?

- A: Yes
- B: No

“It is two hours from Syracuse to Adirondack State Park”

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A: Yes

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C: Only if I tell you something else, too

“It is two hours from Syracuse to Adirondack State Park”

Does this statement make sense?

A: Yes

B: No

C: Only if I tell you something else, too

I've got to also tell you the car's velocity!

Math, physics-style, I: working with dimensions

“The distance from Syracuse to the Adirondacks is two hours”

$$\text{Distance} = \text{Time}$$

This statement makes no sense!

Math, physics-style, I: working with dimensions

“The distance from Syracuse to the Adirondacks is two hours”

$$\text{Distance} = \text{Time}$$

This statement makes no sense!

“The distance from 'Cuse to the Adirondacks is two hours at 100 km per hour”

$$\text{Distance} = \text{Time} \times \frac{\text{Distance}}{\text{Time}}$$

Here the dimensions match on both sides; this is a valid statement.

Math, physics-style, II: working with units

Units of measure (km, hours) follow the rules of algebra.

$$s = (2 \text{ hr}) \times \frac{100 \text{ km}}{1 \text{ hr}}$$
$$s = 200 \text{ km}$$

Velocity is thus a length divided by a time: km/hr, m/s, etc. What about acceleration?

Math, physics-style, II: working with units

“A falling object’s speed increases by 10 meters per second every second.”

$$10 \frac{\frac{\text{meter}}{\text{second}}}{\text{second}}$$

This is really awkward to write...

$$10 \frac{\frac{\text{meter}}{\text{second}}}{\text{second}} = 10 \text{m/s}^2$$

Much better! Even though nobody’s ever seen a “squared second”, this still makes sense mathematically. We can build all kinds of compound units this way.

Math, physics-style, III: compound units

Newton's second law says that force is equal to mass times acceleration. In symbols, $F = ma$. What units could you measure force in?

- A: kg m/s
- B: kg m/s²
- C: m/s²
- D: kg m

Math, physics-style, III: compound units

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- A: kg m/s
- B: kg m/s²
- C: m/s²
- D: kg m

This gets awkward to keep writing, so we define:
 $1 \text{ kg m/s}^2 = 1 \text{ newton}$, abbreviated N.

Demonstrating how to solve problems: How fast is the ping-pong ball going?

- Air pressure P : 10^5 newtons per square meter
- Radius of tube r : 2 cm
- Length of tube L : 2 m
- Mass of ping-pong ball m : 3 g
- Final velocity: v_f (we don't know this yet; it's what we want)

Principles that we know:

- Area $A = \pi r^2$ (from geometry)
- Force due to air pressure $F = PA$ (think about the units: newtons per square meter \times square meters)
- Newton's second law: $F = ma$ (notice: a and A are different!)
- Kinematic relation: $v_f^2 = 2as$, where s is the distance traveled

Math, physics-style, IV: put in the numbers at the end!

Notice:

- Every quantity, even if we know its numerical value, gets a variable
- Comparing the dimensions of your expressions can be used to verify you're thinking about them correctly
- We could have guessed everything above, except for the factors of π and 2, just from the units!
- **Solve everything algebraically before putting in the numbers!**
 - This is *much cleaner*
 - Your algebraic statements also mean things, and you can think as you go
- When you finally do put in the numbers, make sure your units match so you can cancel them

Math, physics-style, IV: put in the numbers at the end!

- Find the force in terms of stuff you know: $F = P(\pi r^2)$
- Find the acceleration that force causes using Newton's second law:

$$\pi Pr^2 = ma \rightarrow a = \frac{\pi Pr^2}{m}$$

- Put this into the kinematic relation:

$$v_f^2 = 2as = 2 \left(\frac{\pi Pr^2}{m} \right) L$$

$$v_f = \sqrt{\frac{2\pi PLr^2}{m}}$$

$$v_f = \sqrt{2 \times \pi \times 10^5 \text{ (N/m}^2\text{)} \times (2 \text{ m}) \times (0.02 \text{ m})^2 / (0.003 \text{ kg})}$$

$$v_f = \sqrt{1.68 \times 10^5 \text{ (N} \times \text{m/kg)}} = \sqrt{1.68 \times 10^5 \text{ (kg m/s}^2\text{)} \times \text{m/kg}}$$

$$v_f = 409 \text{ m/s}$$

The beginning: describing motion (1-D)

Recall that at first, we are only concerned with describing motion.

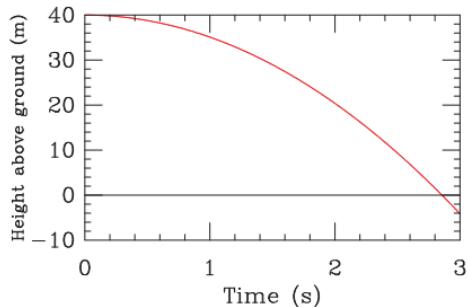
- Most fundamental question: “where is the object I’m talking about?”
- Quantify position using a “number line” marked in meters:
 - Choose one position to be the origin (“zero”) – anywhere will do
 - Choose one direction to be positive
 - Measure everything relative to that
 - Can measure in any convenient units: centimeters, meters, kilometers...
- You’re used to this already, perhaps:
 - Mile markers on highways
 - Yard lines in American football

Equations of motion

Complete description of motion: “Where is my object at each point in time?”

This corresponds to a mathematical function. Two ways to represent these. Suppose I drop a ball off a building, putting the origin at the ground and calling “up” the positive direction:

Graphical representation



Algebraic representation

$$y(t) = (40 \text{ m}) - Ct^2$$

(C is some number; we'll learn what it is Thursday)

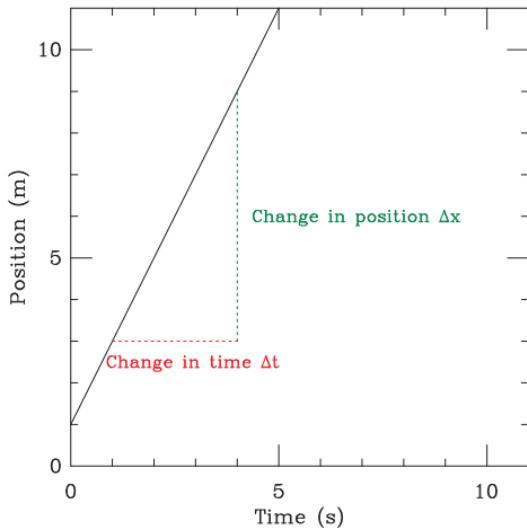
Both let us answer questions like “When does the object hit the ground?”

→ ... the curve's x-intercept

→ ... when $y(t) = 0$

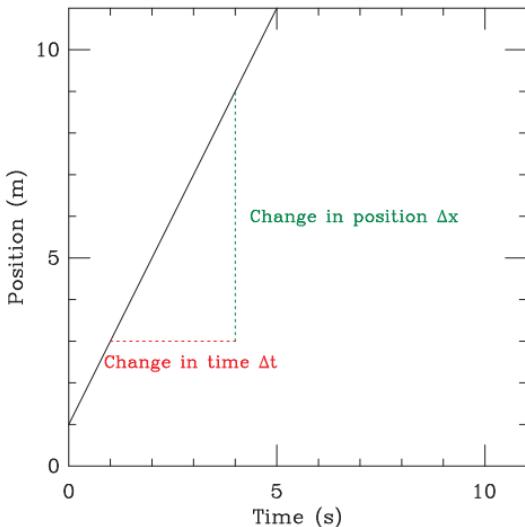
Velocity: how fast position changes

The slope of the position vs. time curve has a special significance. Here's one with a constant slope:



Velocity: how fast position changes

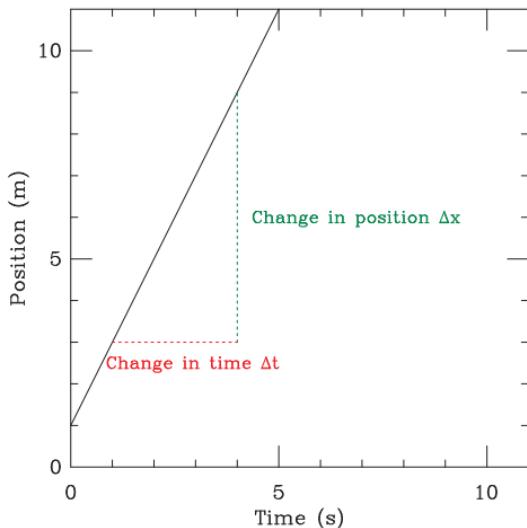
The slope of the position vs. time curve has a special significance. Here's one with a constant slope:



Slope is $\frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t} = \frac{2\text{m}}{1\text{s}} = 2$ meters per second (positive; it could well be negative!)

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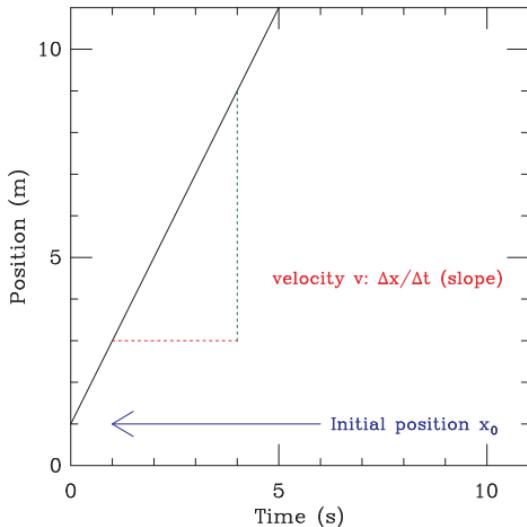


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→ The slope here – change in position over change in time – is the **velocity!** Note that it can be positive or negative, depending on which way the object moves.

Constant-velocity motion: connecting graphs to algebra

If an object moves with constant velocity, its position vs. time graph is a line:



We know the equation of a straight line is $x = mt + b$ (using t and x as our axes).

- m is the slope, which we identified as the velocity
- b is the vertical intercept, which we recognize as the value of x when $t = 0$

We can thus change the variable names to be more descriptive:

$$x(t) = vt + x_0 \text{ (constant-velocity motion)}$$

Going from “equations of motion” to answers

$x(t) = vt + x_0$ is called an *equation of motion*; in this case, it is valid for constant-velocity motion.

It gives you the same information as a position vs. time graph, but in algebraic form.

To solve real problems, we need to be able to translate physical questions into algebraic statements:

- “If a car starts at milepost 30 and drives at 50 mph, where is it an hour later?”

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- “If a car starts at milepost 30 and drives at 50 mph, where is it an hour later?”
 - Using $x(t) = x_0 + vt$, with $x_0 = 30$ mi and $v = 50 \frac{\text{mi}}{\text{hr}}$, calculate x at $t = 1$ hr

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- “When does a falling object hit the ground?”

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- “When does a falling object hit the ground?”
 - If the ground is at $y = 0$, then we ask: “What is the value of t when $y = 0$? ”
- “When do two moving objects meet?”

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 - If the ground is at $y = 0$, then we ask: “What is the value of t when $y = 0$? ”
- “When do two moving objects meet?”
 - Write down $x_1(t)$ and $x_2(t)$, then ask “At what time does $x_1 = x_2$? ”

A rough problem-solving guide for constant-velocity motion

A general framework for solving constant-velocity problems algebraically:

- ❶ Decide on a coordinate system: where is $x = 0$, and which way is positive?
- ❷ Write down the equation of motion $x(t) = x_0 + vt$ for each object
- ❸ Ask “How can I translate the thing I’m looking for into an algebraic statement?”
- ❹ Do the algebra!