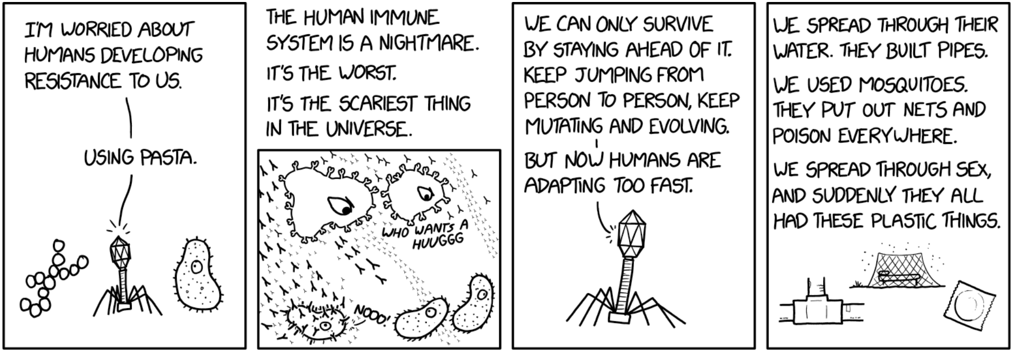
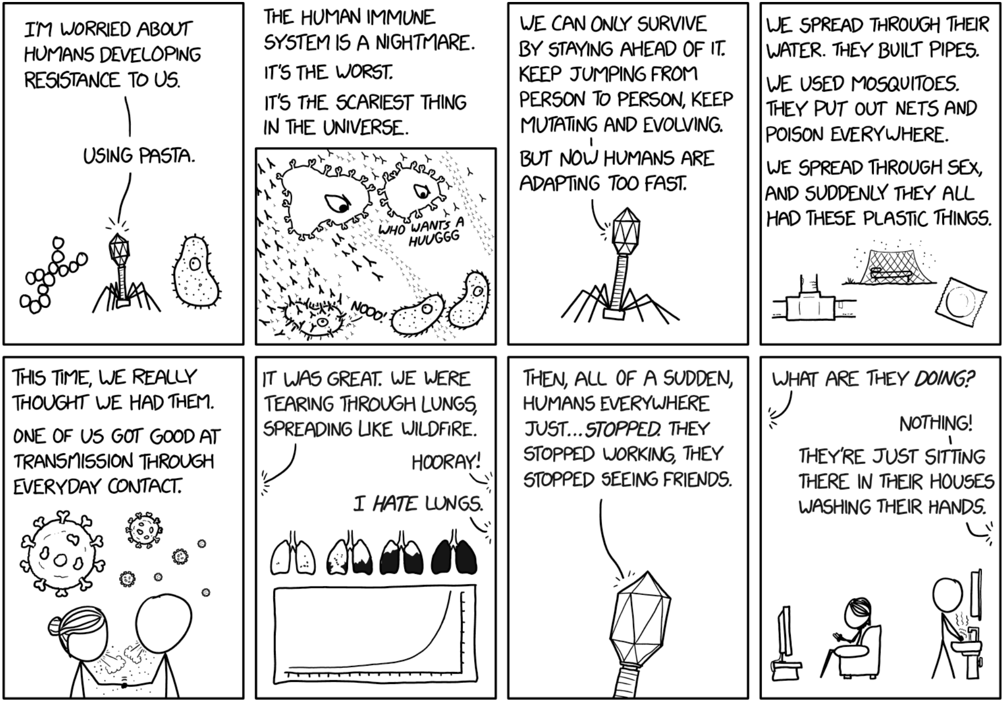
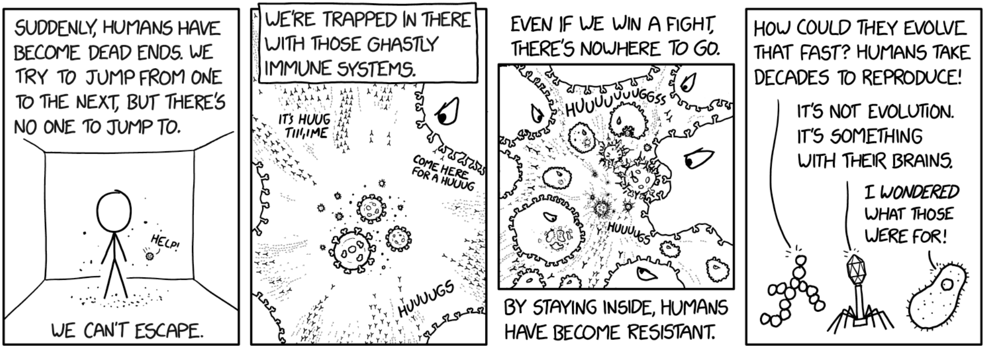
Exam 3 review; the process of science

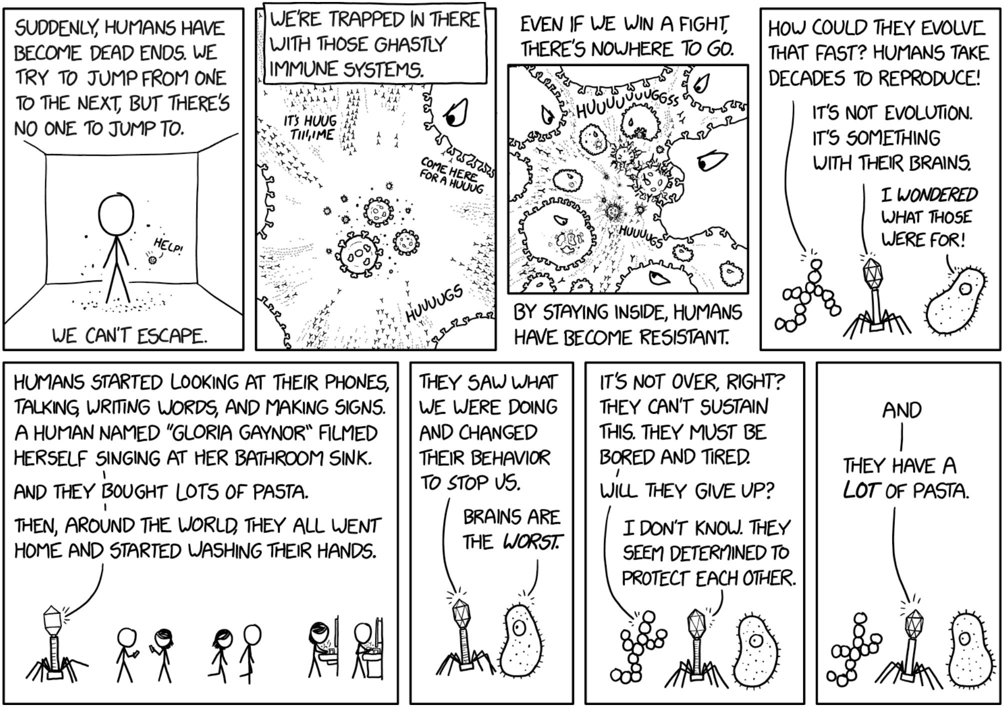
Physics 211
Syracuse University, Physics 211 Spring 2020
Walter Freeman, with Matt Rudolph
Cartoons by Randall Munroe :)

April 1, 2020


I'M WORRIED ABOUT HUMANS DEVELOPING RESISTANCE TO US.
USING PASTA.
THE HUMAN IMMUNE SYSTEM IS A NIGHTMARE.
IT'S THE WORST.
IT'S THE SCARIEST THING IN THE UNIVERSE.
WHO WANTS A HUUGGG
NOOO!
WE CAN ONLY SURVIVE BY STAYING AHEAD OF IT. KEEP JUMPING FROM PERSON TO PERSON, KEEP MUTATING AND EVOLVING.
BUT NOW HUMANS ARE ADAPTING TOO FAST.
WE SPREAD THROUGH THEIR WATER. THEY BUILT PIPES.
WE USED MOSQUITOES. THEY PUT OUT NETS AND POISON EVERYWHERE.
WE SPREAD THROUGH SEX, AND SUDDENLY THEY ALL HAD THESE PLASTIC THINGS.


I'M WORRIED ABOUT HUMANS DEVELOPING RESISTANCE TO US.
USING PASTA.
THE HUMAN IMMUNE SYSTEM IS A NIGHTMARE.
IT'S THE WORST.
IT'S THE SCARIEST THING IN THE UNIVERSE.
WHO WANTS A HUUGGG
NOOO!
WE CAN ONLY SURVIVE BY STAYING AHEAD OF IT. KEEP JUMPING FROM PERSON TO PERSON, KEEP MUTATING AND EVOLVING.
BUT NOW HUMANS ARE ADAPTING TOO FAST.
WE SPREAD THROUGH THEIR WATER. THEY BUILT PIPES.
WE USED MOSQUITOES. THEY PUT OUT NETS AND POISON EVERYWHERE.
WE SPREAD THROUGH SEX, AND SUDDENLY THEY ALL HAD THESE PLASTIC THINGS.
THIS TIME, WE REALLY THOUGHT WE HAD THEM.
ONE OF US GOT GOOD AT TRANSMISSION THROUGH EVERYDAY CONTACT.
IT WAS GREAT. WE WERE TEARING THROUGH LUNGS, SPREADING LIKE WILDFIRE.
HOORAY!
I *HATE* LUNGS.
THEN, ALL OF A SUDDEN, HUMANS EVERYWHERE JUST... *STOPPED*. THEY STOPPED WORKING, THEY STOPPED SEEING FRIENDS.
WHAT ARE THEY *DOING?*
NOTHING!
THEY'RE JUST SITTING THERE IN THEIR HOUSES WASHING THEIR HANDS.


SUDDENLY, HUMANS HAVE BECOME DEAD ENDS. WE TRY TO JUMP FROM ONE TO THE NEXT, BUT THERE'S NO ONE TO JUMP TO.
HELP!
WE CAN'T ESCAPE.
WE'RE TRAPPED IN THERE WITH THOSE GHASTLY IMMUNE SYSTEMS.
IT'S HUUG TIIIIME
COME HERE FOR A HUUUG
HUUUUGS
EVEN IF WE WIN A FIGHT, THERE'S NOWHERE TO GO.
HUUUUUUUGGSS
HUUUUGS
BY STAYING INSIDE, HUMANS HAVE BECOME RESISTANT.
HOW COULD THEY EVOLVE THAT FAST? HUMANS TAKE DECADES TO REPRODUCE!
IT'S NOT EVOLUTION. IT'S SOMETHING WITH THEIR BRAINS.
I WONDERED WHAT THOSE WERE FOR!



"Pathogen Resistance", `xkcd` *#2287, by Randall Munroe,* `cc-by-nc`

Announcements

- Exam 3 will start Tuesday at 1pm Syracuse time and will be due Wednesday at 1pm Syracuse time.
- We will be available Tuesday morning during class time for a last-minute review session before the exam, if anyone is interested
- No recitations next Wednesday (we'll be starting grading)

- Friday's recitation will be a tour through part of the practice exam:
  - There are eight questions, like before
  - Each recitation section will focus on two of the questions
  - You are free to attend *as many as you want* if you want extra study practice with friends
  - This won't be graded for accuracy; coaches/TA's will be answering questions and helping folks
  - I'll post video solutions over the weekend (probably Sunday)

- Homework 11 is posted; it is due next Tuesday before the exam.
- Homework 10 solutions will be posted as soon as I make them
- Don't forget to submit your recitation journals: Wednesday's is due Friday, Friday's will be due Sunday

Exam 3

Format:

- We will post a PDF of the questions Tuesday at 1PM Syracuse time; your answers are due 24 hours later, Wednesday 1PM.
- You can either:
  - Write answers on your own paper, scan it, and send it to us
  - Print the PDF and write answers on it, then scan it and send it to us
  - Write answers on the PDF using a tablet and stylus, and send it to us electronically
- The exam may be slightly longer than an in-class exam, but not by that much
- We anticipate that a prepared student will be able to finish the exam in (at most) two hours

During the exam:

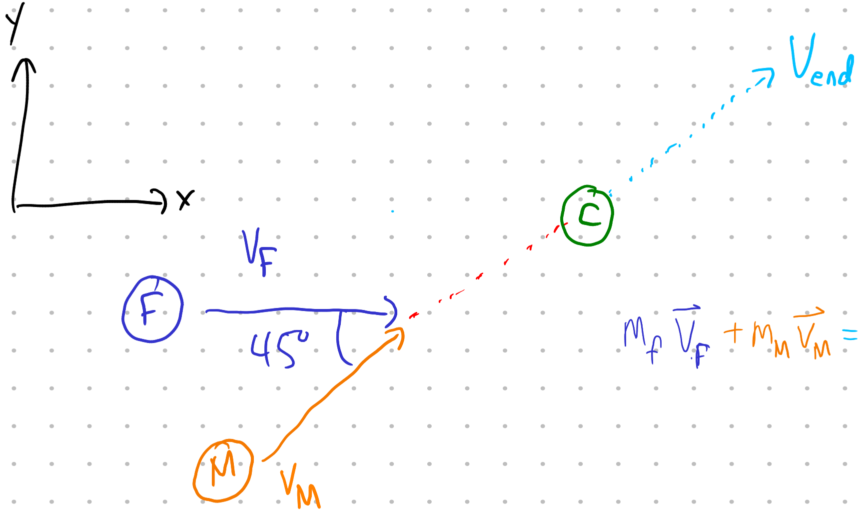
- You may consult anything from this class (slides, your notes, our notes, videos, textbook)
- You may ask teaching staff questions if you are not clear about what a question is describing or asking
- You may *not* ask other people for help or search for answers on the internet; we expect you to do the exam with your own skill, aided by your notes and class material.

Major topics:

- Conservation of momentum
- The work-energy theorem and conservation of energy.

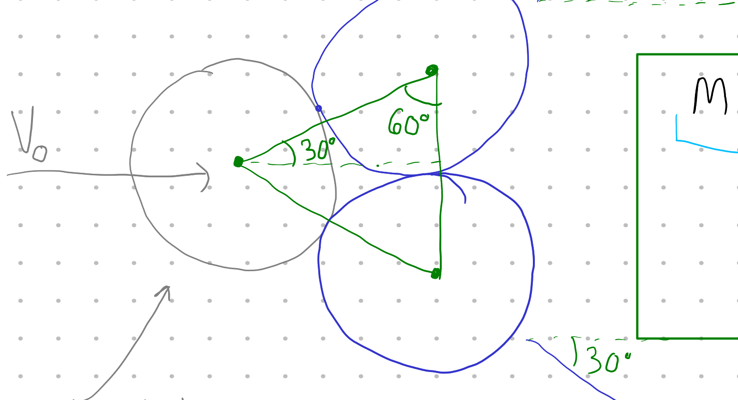
Minor topics:

- Power (HW #11)
- Process of science: measurement bias



$$m_f \vec{V}_F + m_M \vec{V}_M = (m_M + m_F + m_C)\vec{V}_{end}$$

- Collision $\rightarrow$ use conservation of $\vec{p}$
- Elastic collision $\rightarrow$ KE also conserved.



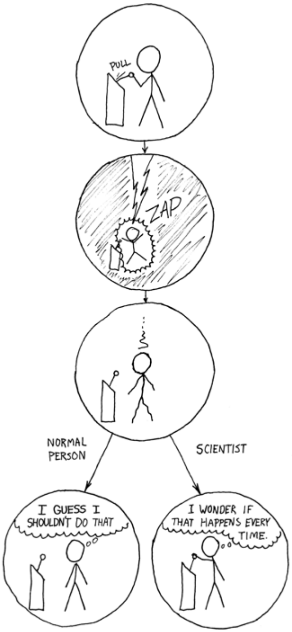
final velocity V_c – direction unknown

$$\underbrace{MV_0 = MV_c + 2mv\cos 30°}_{\text{cons. of } \vec{p} \text{ in } x}$$

$$\frac{1}{2}MV_0^2 = \frac{1}{2}MV_c^2 + 2\,\frac{1}{2}mv^2$$

$$Y:\ 0 = mV_1 \sin 30° - mV_2 \sin 30°$$

The process of science

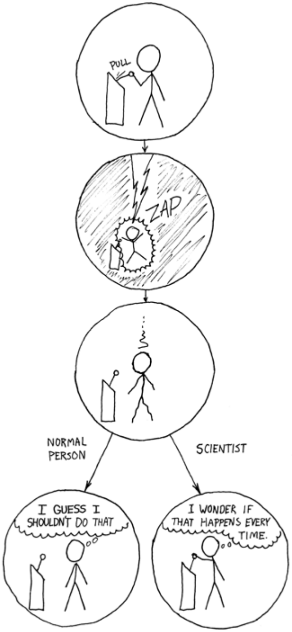


We've taken a tour through the main principles of mechanics, and you have all the major ideas of classical physics now at your fingertips: energy, motion, force, momentum, etc.

But let's step back for a bit. The development of mechanics was part of the *scientific revolution* – the development of a new way to understand our world.

But what is science?

The process of science



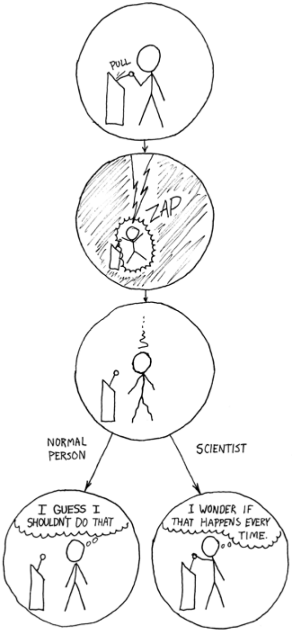
We've taken a tour through the main principles of mechanics, and you have all the major ideas of classical physics now at your fingertips: energy, motion, force, momentum, etc.

But let's step back for a bit. The development of mechanics was part of the *scientific revolution* – the development of a new way to understand our world.

But what is science?

How is science different from other ways of examining our world?

The process of science



We've taken a tour through the main principles of mechanics, and you have all the major ideas of classical physics now at your fingertips: energy, motion, force, momentum, etc.

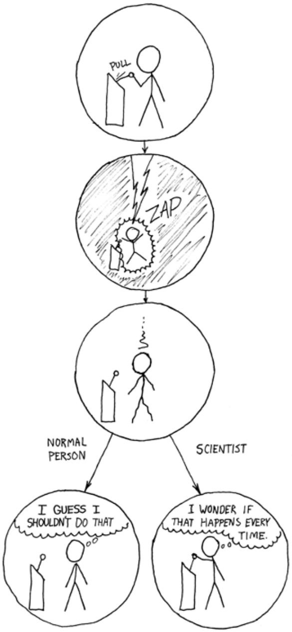
But let's step back for a bit. The development of mechanics was part of the *scientific revolution* – the development of a new way to understand our world.

But what is science?

How is science different from other ways of examining our world?

What does science look like when it is being done well?

The process of science



We've taken a tour through the main principles of mechanics, and you have all the major ideas of classical physics now at your fingertips: energy, motion, force, momentum, etc.

But let's step back for a bit. The development of mechanics was part of the *scientific revolution* – the development of a new way to understand our world.

But what is science?

How is science different from other ways of examining our world?

What does science look like when it is being done well?

How can the scientific process be derailed – on purpose or by accident? (Next week!)

The history of natural philosophy

To understand the scientific revolution in perspective, we need to take a tour through the history of both astronomy and natural philosophy.

In ancient Greece, astronomy was thought of as separate from (and lesser than) natural philosophy.

- **Astronomy:** How can I predict where Mars will be in the sky a month from now?
  - Concerned with mundane tasks like getting sailors home safe and predicting horoscopes
  - Not a proper pursuit for the *truly* enlightened, since you had to get your hands dirty with data
- **Natural philosophy:** What is the underlying, transcendent Truth of nature?

While astronomers had to do some natural philosophy, and while natural philosophers had to mess with data a bit, there was still a divide.

Greco-Egyptian astronomy

Most of our knowledge of astronomy from the time comes from Ptolemy.

His work was concerned with creating a method for calculating where things would be in the sky. Stars are easy; planets are much harder.

Ptolemy used the things he “knew” from Aristotle, and modified them in awkward ways to make them fit his observations:

- The Earth is at the center of everything
- All the planets move in complicated patterns required to explain their motion

Ptolemy’s model made remarkably accurate predictions. There were some errors, which were fixed up centuries later by the Muslim astronomers that passed down his work and honed his calculations.

What's in the middle?

In the 1500's Copernicus proposed that instead the Sun was at the center, and the planets went around it in circles.

This explained the rough contours of the motion of planets more simply than Ptolemy, but actually *didn't* get the details right.

There was an odd preface, added by the publisher (paraphrased):

"This is unusual. But it is just mathematics; it should be judged on whether or not it makes accurate predictions; this is separate from whether it contains actual philosophical truth!"

In the next century or so, two things happened:

- Galileo saw things through a telescope that showed that the Earth *couldn't* be at the center
- Tycho Brahe and his assistants Sophie and Kepler made very precise measurements of the motions of the planets

Kepler and Newton

Kepler had a dilemma:

- He was a strong supporter of Copernicus' model
  - The Sun at the center
  - Planets travel in circles around it

Kepler and Newton

Kepler had a dilemma:

- He was a strong supporter of Copernicus' model
  - The Sun at the center
  - Planets travel in circles around it

- He knew how precise his data were
- *No* arrangement of circular orbits fit the data:
- Mars' position always had an error of at least 1/8 of a degree

Eventually he realized that if the orbits were *ellipses*, he could fit the data perfectly.

He didn't know *why* the planets moved in ellipses, but he now had a model. (He wasn't good enough at mathematics to figure out the "why".)

Kepler and Newton

Newton was.

Kepler's observation that the planets moved in elliptical orbits was a perfect playground:

- The only meaningful force in space is gravity
- He realized that $\vec{F} = m\vec{a}$ together with $F_g = \frac{GMm}{r^2}$ could explain elliptical orbits
- ... and $\vec{F} = m\vec{a}$ could explain terrestrial motion, too!

(Getting from $\frac{GMm}{r^2} = ma$ to elliptical orbits required Newton's mathematical skill, but we have a computer...)

Properties of science

As we see in the story of its birth, science – as a means of seeking truth about nature – has a few fundamental properties:

- **Empiricism:** the ultimate authority is what we measure about the world around us, not what we think.
- The new scientific approach to mechanics started with observations: planet motion, Newton's pendulums, falling objects...

- **Self-skepticism:** someone making a scientific claim should actively search for things that might prove themselves wrong
- Kepler was convinced planetary orbits were circles... until the data convinced him otherwise

- **Universality:** the laws of nature apply in all places and times, and to all things (including humans)
- Newton was able to explain *all* motion with one set of principles, in space and on Earth

- **Objectivity:** scientific ideas, or the evaluation of them, should be independent of any particular human perspective
- Earth was no longer given a privileged place or special rules

Principles that come from these:

These things are difficult and many honest scientists (meaning: anyone who talks about the natural world) slip up.

These principles are safeguards to protect us from being too convinced of things that are not true. But it is possible to be a good, honest scientist, and make mistakes.

Of course, it is also possible to be dishonest: to intentionally warp the process of science to convince people of things that are not true.

Principles that come from these: empiricism

A model is only valid within the realm of data against which it has been checked.

- Precision: is the law of gravity valid to one part in a billion? One part in a trillion?
  - "Equivalence" (all objects fall at the same rate in a vacuum): holds to one part in 10^{17}
  - Universal gravitation: **Not quite true in regions of strong gravity!**

- Scope and scale: Is Newtonian mechanics valid for very fast things? Things as large as a galaxy? Things as small as an atom?
  - Very fast things: **not quite**, since close to the speed of light space and time get mixed up
  - Very large things: Yes, things as large as galaxies and beyond (but this requires dark matter)
  - Very small things: **no**, since quantum mechanics changes definitions of "position"

Principles that come from these: empiricism

A model is only valid within the realm of data against which it has been checked.

- Precision: is the law of gravity valid to one part in a billion? One part in a trillion?
  - "Equivalence" (all objects fall at the same rate in a vacuum): holds to one part in 10^{17}
  - Universal gravitation: **Not quite true in regions of strong gravity!**
- Scope and scale: Is Newtonian mechanics valid for very fast things? Things as large as a galaxy? Things as small as an atom?
  - Very fast things: **not quite**, since close to the speed of light space and time get mixed up
  - Very large things: Yes, things as large as galaxies and beyond (but this requires dark matter)
  - Very small things: **no**, since quantum mechanics changes definitions of "position"
- Universality helps with this, but we have to be careful
  - We don't need to drop every rock off a cliff to understand projectile motion...
  - ... but it's hard to know exactly what limits we have to probe

Principles that come from these: self-skepticism

It's the duty of the claimer to search for experiments that they can do to possibly prove themselves wrong.

- The most powerful evidence for an idea is an experiment that will produce something unexpected if you're right, but can conclusively *disprove* your idea if you're wrong

- In 1917 Einstein proposed a radical new way of thinking about gravity
- ... and calculated from it two things, one of which could be tested the next time there was an eclipse
- If Einstein was wrong, we'd know it immediately.

Principles that come from these: self-skepticism

It's the duty of the claimer to search for experiments that they can do to possibly prove themselves wrong.

- The most powerful evidence for an idea is an experiment that will produce something unexpected if you're right, but can conclusively *disprove* your idea if you're wrong

- In 1917 Einstein proposed a radical new way of thinking about gravity
- ... and calculated from it two things, one of which could be tested the next time there was an eclipse
- If Einstein was wrong, we'd know it immediately.

- These experiments need to be as diverse as possible: this is hard, since you have to check things you're not familiar with

Principles that come from these: universality

It is important to **reproduce scientific results** by repeating experiments to check their accuracy.

If an experiment should work the same way everywhere, then an important check is to make sure that someone else, in a different place and time, gets the same result.

Principles that come from these: objectivity

Maintaining **diversity** in the scientific community is important to ensure valid conclusions.

Since results shouldn't depend on the particular perspective of the scientists working on them, science benefits from having people with different experiences and backgrounds work on a problem.

That way, any "blind spot" that people with a particular background tend to have will be caught by people from a different background.

How does this go wrong?

$F_g = \frac{GMm}{r^2}$ + a small correction

One example of how this goes wrong: **measurement bias.**

Using limited, biased data will give you a biased result, accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of g nearby to analyze them

How does this go wrong?

One example of how this goes wrong: **measurement bias.**

Using limited, biased data will give you a biased result, accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of g nearby to analyze them

- They got a team of people with sensitive gravitometers to help make them...

How does this go wrong?

One example of how this goes wrong: **measurement bias.**

Using limited, biased data will give you a biased result, accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of g nearby to analyze them

- They got a team of people with sensitive gravitometers to help make them...
- ... they didn't want to get them wet (so they avoided puddles) ...

How does this go wrong?

One example of how this goes wrong: **measurement bias.**

Using limited, biased data will give you a biased result, accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of g nearby to analyze them

- They got a team of people with sensitive gravitometers to help make them...
- ... they didn't want to get them wet (so they avoided puddles) ...
- ... so they biased their sample toward higher terrain!

How does this go wrong?

One example of how this goes wrong: **measurement bias.**

Using limited, biased data will give you a biased result, accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of g nearby to analyze them

- They got a team of people with sensitive gravitometers to help make them...
- ... they didn't want to get them wet (so they avoided puddles) ...
- ... so they biased their sample toward higher terrain!
- Once this was realized and corrected, the signal went away

How does this go wrong?

One example of how this goes wrong: **measurement bias.**

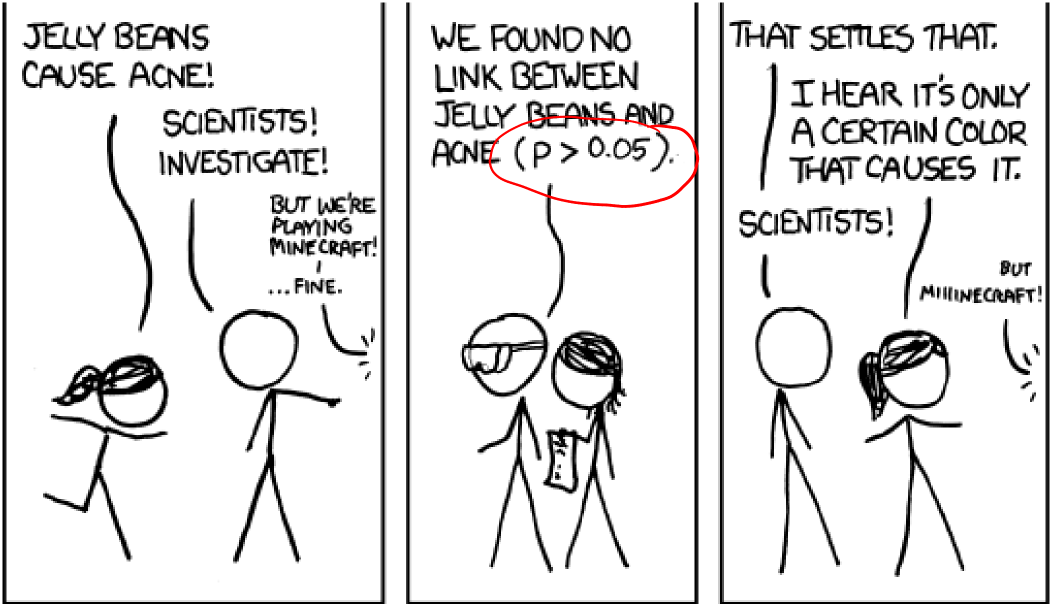
Using limited, biased data will give you a biased result, accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that the law of gravity might depend on the type of matter
- They made some very careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of g nearby to analyze them

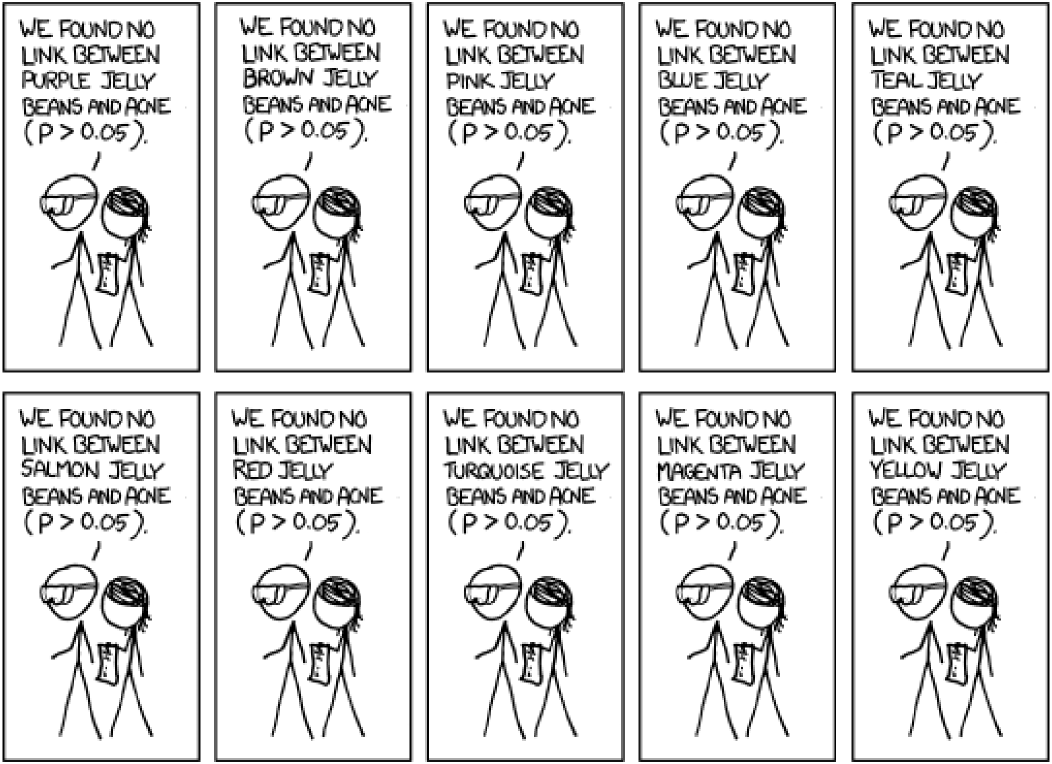
- They got a team of people with sensitive gravitometers to help make them...
- ... they didn't want to get them wet (so they avoided puddles) ...
- ... so they biased their sample toward higher terrain!
- Once this was realized and corrected, the signal went away
- Nobody meant to deceive anyone here

Examples: reporting bias

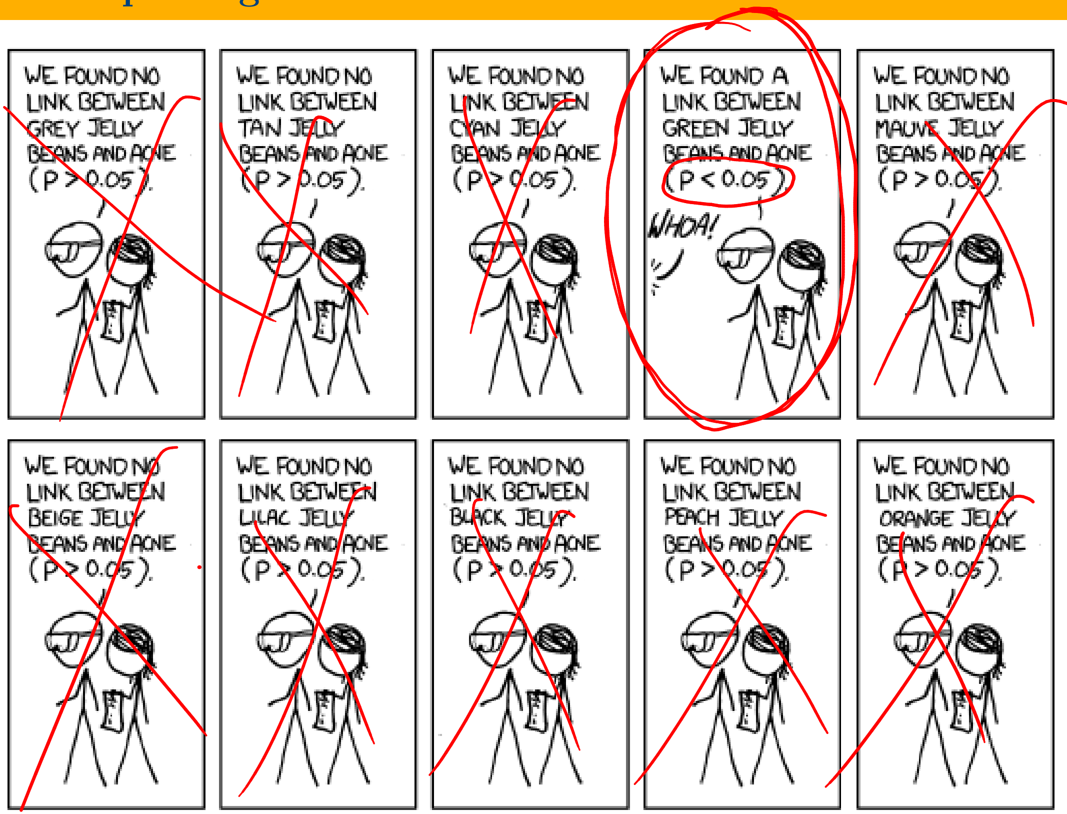


$p > 0.05$: "whatever we found, there's more than a 5% chance that it is just a coincidence"

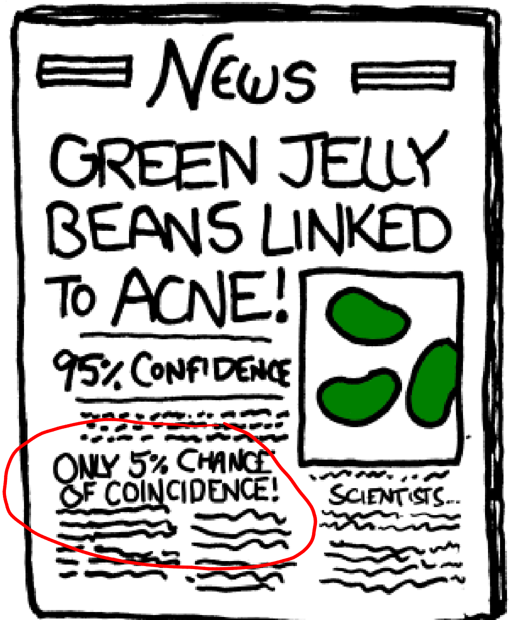
Examples: reporting bias



Examples: reporting bias



Examples: reporting bias

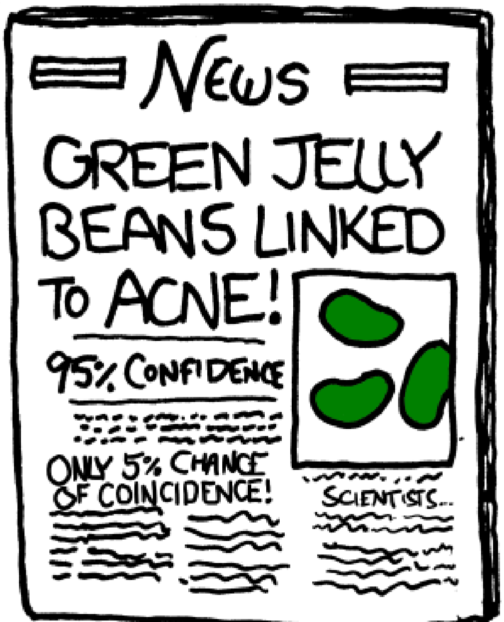


xkcd #882, by Randall Munroe: cc-by-nc.

Reporting only an interesting/profitable/exciting piece of data, and ignoring the rest, leads to flawed conclusions!

This is particularly worrying in medical research.

Examples: reporting bias



xkcd #882, by Randall Munroe: cc-by-nc.

Reporting only an interesting/profitable/exciting piece of data, and ignoring the rest, leads to flawed conclusions!

This is particularly worrying in medical research.

We will ask a simple question about the dangers of measurement bias on Exam 3.

Review: Conservation of momentum

If a collection of objects exerts forces only on each other, then their *total momentum* $\vec{p} = m\vec{v}$ is constant.

During a collision or explosion, the forces involved are so large that during that moment, external forces don't matter.

Any time you have a problem with a collision or explosion, this means you will need to use *conservation of momentum*. It is also useful in any other situations with *no external forces*.

Remember: **momentum is a vector.** If two objects collide and are moving in two dimensions:

$$m_1\vec{v}_{1_i} + m_2\vec{v}_{2_i} = m_1\vec{v}_{1_f} + m_2\vec{v}_{2_f}$$

... but this is true separately for $x-$ and $y-$components:

$$m_1 v_{1_{x\,i}} + m_2 v_{2_{x\,i}} = m_1 v_{1_{x\,f}} + m_2 v_{2_{x\,f}}$$

$$m_1 v_{1_{y\,i}} + m_2 v_{2_{y\,i}} = m_1 v_{1_{y\,f}} + m_2 v_{2_{y\,f}}$$

Types of collisions

Elastic collision:

- Momentum is conserved
- Objects bounce back after the collision
- Kinetic energy is also conserved

$\longrightarrow$ System of equations:

$$\sum p_i = \sum p_f$$

and $$\sum KE_i = \sum KE_f$$

Types of collisions

Elastic collision:

- Momentum is conserved
- Objects bounce back after the collision
- Kinetic energy is also conserved

Partially inelastic collision:

- Momentum is conserved
- Objects bounce back, but slower
- Some kinetic energy is lost

Types of collisions

Elastic collision:

- Momentum is conserved
- Objects bounce back after the collision
- Kinetic energy is also conserved

Partially inelastic collision:

- Momentum is conserved
- Objects bounce back, but slower
- Some kinetic energy is lost

Fully inelastic collision:

- Momentum is conserved
- Objects stick together after the collision
- Some kinetic energy is lost

Review: The work-energy theorem

Work is the change in kinetic energy.

$$\frac{1}{2}mv_i^2 + W_{\text{all}} = \frac{1}{2}mv_f^2$$

Work $= \vec{F} \cdot \Delta\vec{s}$, or ...

- $F_{\parallel}\Delta s$ (component of force parallel to motion, times the distance moved)
- $F(\Delta s)_{\parallel}$ (force, times the distance moved in the direction of that force)
- $F\Delta s \cos\theta$ (either way, this is the trigonometry you wind up with)

all equivalent

Note that:

- Forces that are in the direction of motion increase the speed of objects, and do positive work
- Forces that are opposite the direction of motion decrease the speed of objects, and do negative work
- Forces perpendicular to the direction of motion do no work at all

Review: Potential energy

Potential energy is an alternate way of keeping track of the work done by conservative forces:

- $PE_{\text{grav}} = mgh$
- $PE_{\text{spring}} = \frac{1}{2}kx^2$

If you're tracking the work due to gravity or elasticity using potential energy, don't also include it in your work term. See the next slide:

Review: Conservation of energy

$$\frac{1}{2}mv_i^2 + W_{all} = \frac{1}{2}mv_f^2$$

$$\mathrm{PE_i} + \frac{1}{2}mv_i^2 + W_{\text{other}} = \mathrm{PE_f} + \frac{1}{2}mv_f^2$$

Review: Conservation of energy

$$\begin{array}{ccccccccc} \mathrm{PE_i} & + & \frac{1}{2}mv_i^2 & + & W_{\text{other}} & = & \mathrm{PE_f} & + & \frac{1}{2}mv_f^2 \\ \text{(initial PE)} & + & \text{(initial KE)} & + & \text{(other work)} & = & \text{(final PE)} & + & \text{(final KE)} \end{array}$$

Review: Conservation of energy

$$\mathrm{PE_i} + \tfrac{1}{2}mv_i^2 + W_{\text{other}} = \mathrm{PE_f} + \tfrac{1}{2}mv_f^2$$

(initial PE) + (initial KE) + (other work) = (final PE) + (final KE)

(total initial mechanical energy) + (other work) = (total final mechanical energy)

Review: Conservation of energy

$$\text{PE}_\text{i} \quad + \quad \tfrac{1}{2}mv_i^2 \quad + \quad W_\text{other} \quad = \quad \text{PE}_\text{f} \quad + \quad \tfrac{1}{2}mv_f^2$$

$$\text{(initial PE)} \quad + \quad \text{(initial KE)} \quad + \quad \text{(other work)} \quad = \quad \text{(final PE)} \quad + \quad \text{(final KE)}$$

$$\text{(total initial mechanical energy)} \quad + \quad \text{(other work)} \quad = \quad \text{(total final mechanical energy)}$$

Since conservation of energy is the broadest principle in science, it's no surprise that we can do this!

$$W_{grav} = F_g (\Delta s)_{\parallel} = mg\,(\quad -y_f)$$

Review: Power

Power is just the rate of doing work.
Since velocity is the rate of being displaced, this gives us:

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

Review: "Setting up problems"

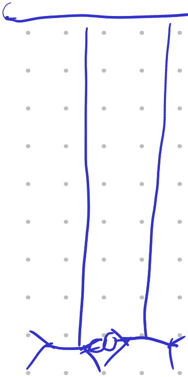
In the next few slides, I'd like to discuss how to set up a few problems.
We won't actually do the mathematics; we'll just draw cartoons of different moments in the motion and talk about what techniques we can use to solve them.

Use work/energy when:

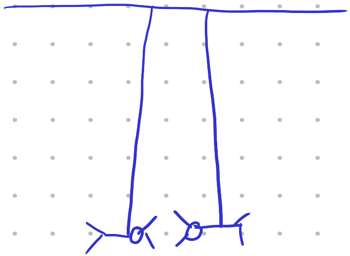
- You have clear "before" and "after" pictures
- You have an expression for the work done by all forces in between
- You don't know and don't care about time
- The thing you're interested in appears in the work-energy theorem somehow

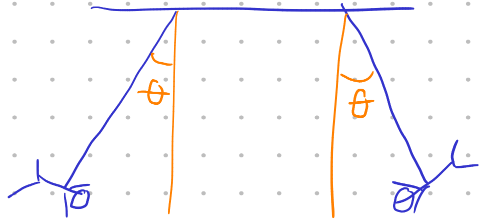
Use conservation of momentum when:

- You have two objects colliding or one object exploding (separating into pieces)
- You need to relate the state *right before* the collision/explosion to the state *right after*
- **or** you have some other situation where there are no external forces



"explosion"



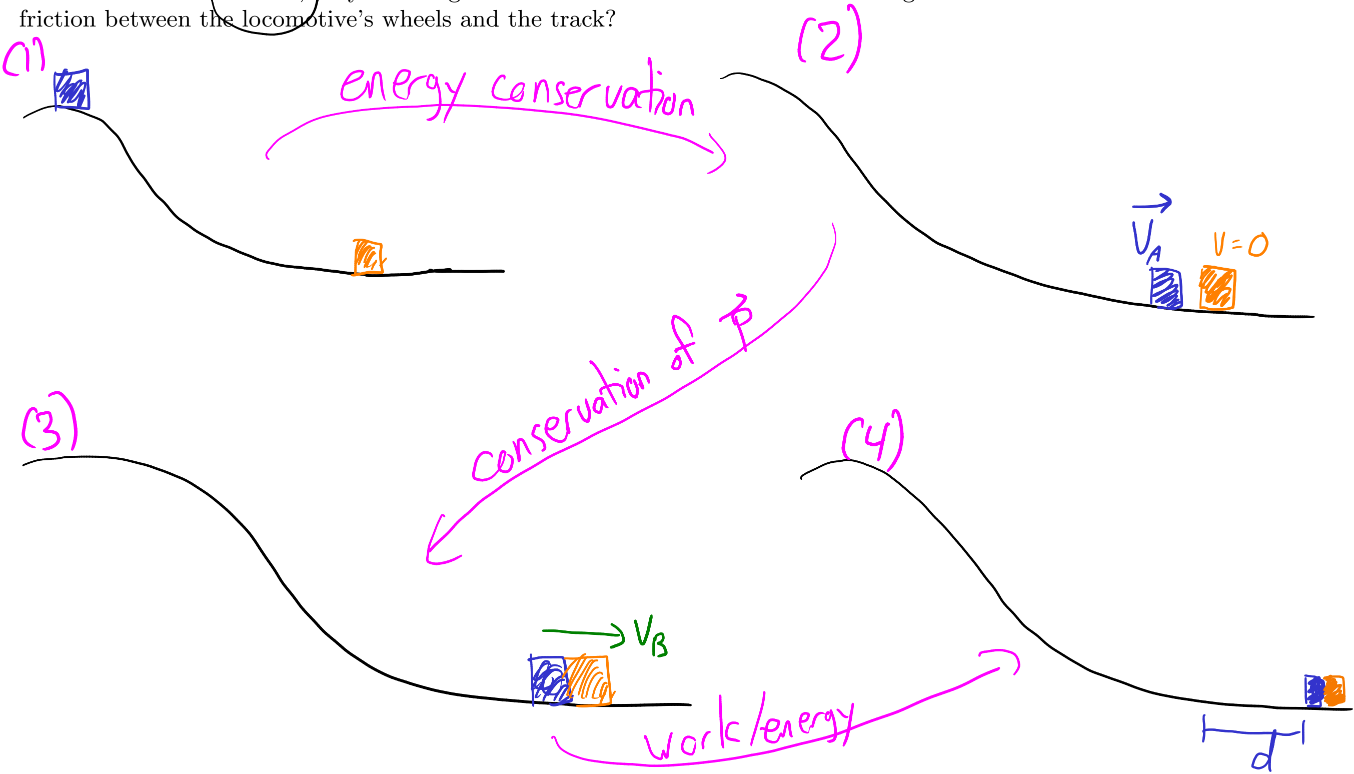


momentum conserved

momentum not conserved

$\vec{p}$ not conserved

A train car rolls down a hill of height h. At the bottom of the hill there is a locomotive at rest with its brakes engaged. When the two cars collide, they stick together and slide a distance d before coming to rest. What is the coefficient of friction between the locomotive's wheels and the track?



A mad scientist wants to set a ski-jump record, and has built a rocket pack to help her do this. She builds a ramp made out of snow with a length L and height h on a flat snowy surface, then fires her rocket pack while starting a distance d behind the ramp. If the rocket provides a constant force F and she deactivates her rocket pack once she jumps off the ramp, how far will she fly?

What would you all like to talk about?