Two competing theories:

(1) The number of balls which bounce off equals the number of balls which I dropped

(2) Energy and momentum are conserved.

All science is either physics or stamp collecting.

-- Ernest Lord Rutherford, discoverer of atomic nucleus

Two competing theories:

physics

stamp-collecting

(1) The number of balls which bounce off equals the number of balls which I dropped

(2) Energy and momentum are conserved.

Science
(i.e., not stamp collecting)

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Aside

- The previous slide was just my theory of science...
- Can you think of a way to test it / disprove it / challenge it?

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Philosophy of Science

Science may be described as the art of systematic over-simplification.
Karl Popper

In so far as a scientific statement speaks about reality, it must be falsifiable; and in so far as it is not falsifiable, it does not speak about reality.
Karl Popper

Under normal conditions the research scientist is not an innovator but a solver of puzzles, and the puzzles upon which he concentrates are just those which he believes can be both stated and solved within the existing scientific tradition. Thomas Kuhn

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Grand Unified Theory

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Newton's Third Law

Every action has an equal and opposite reaction

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Which experiences the bigger force?

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Newton's Second Law

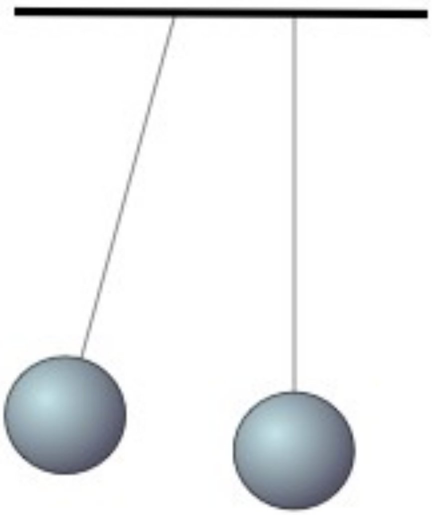
Force ≡ rate of change of "quantity of motion"
↳ momentum, p

Change (momentum of obj 1)
= − Change (momentum of obj 2)
⇓
no change in total momentum
"Conservation"

By the way --

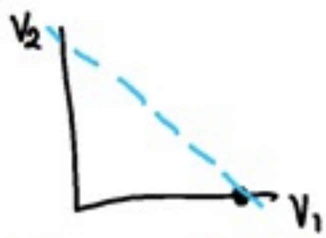
What was Newton's First Law?

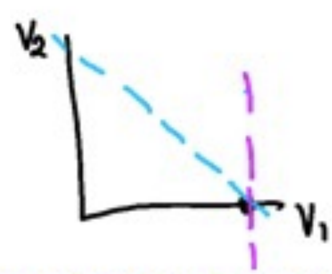
Simplify, simplify, simplify



How many laws do we need?

We want to predict 2 things, v_1 & v_2





One law tells us one thing (if v_2 goes up, v_1 goes down by the same amount... but how much?)

A second law could give us a unique answer... but what is the second law?

Conservation of energy

Realisation:

If objects only exert forces while they're touching (and it takes time to exert a force), then the force must only last while they are travelling at the same velocity.

P_1 goes up by the same amount that P_2 goes down

But v_1 & v_2 are the same.

⇓

Then $P_1 \times v_1$ goes up by the same amount that $P_2 \times v_2$ goes down.

Conclusion:

There is a second thing which is conserved, which we'll call "energy of motion" or kinetic energy:

How does this help?

(It turns out (calculus) that Fv is the rate of change of $\frac{1}{2}mv^2$)

Change (KE of obj 1)
= -Change (KE of obj 2)

⇓

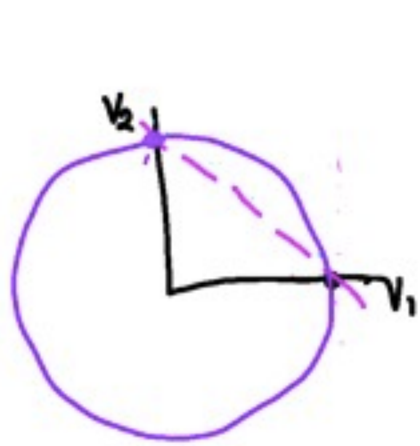
Total KE doesn't change

So this thing which doesn't change must look like $v_1^2+v_2^2$

Those of you who remember Pythagoras may know that's how you find a length

cons of p: v_1, v_2 stay on a line

cons of E: v_1, v_2 stay on a circle
(i.e., a fixed distance from 0)



NOW is that an explanation?

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Notice I needed to *assume* no action at a distance ("locality")

- What happens if I drop an Apple?

Is momentum conserved?

Is energy conserved?

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Three possible solutions

1. Energy conservation is only true for local forces, not in general
2. There's a*nother* sort of energy – "potential" energy – which goes down while the kinetic energy of the falling ball increases.

We simply make this up!

We figure out how much kinetic energy the apple would have by the time it hit the ground, and say "that's how much energy it has the potential to acquire"

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Force fields

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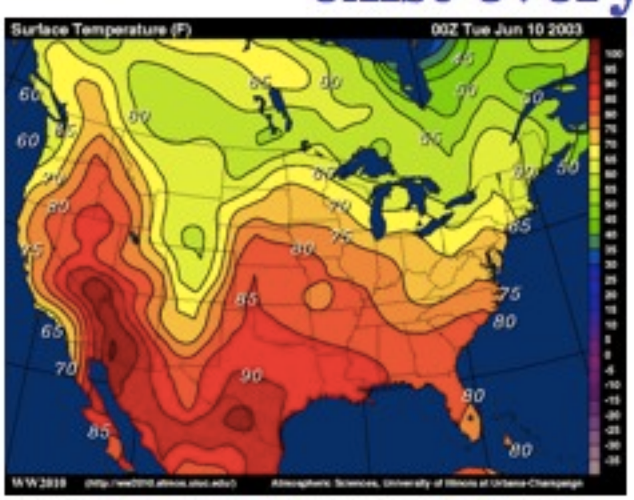
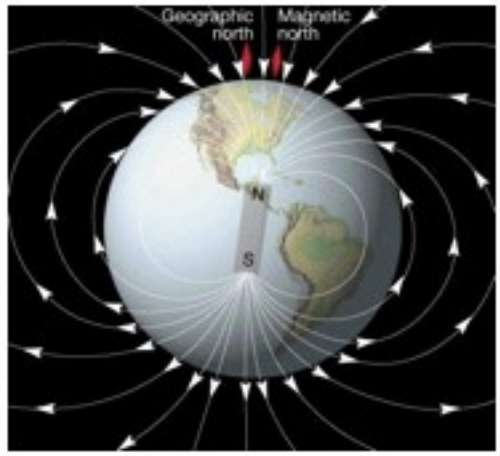
"Fields" are just things which exist everywhere



Temperature is a field: each point on the earth can be labelled with its temperature

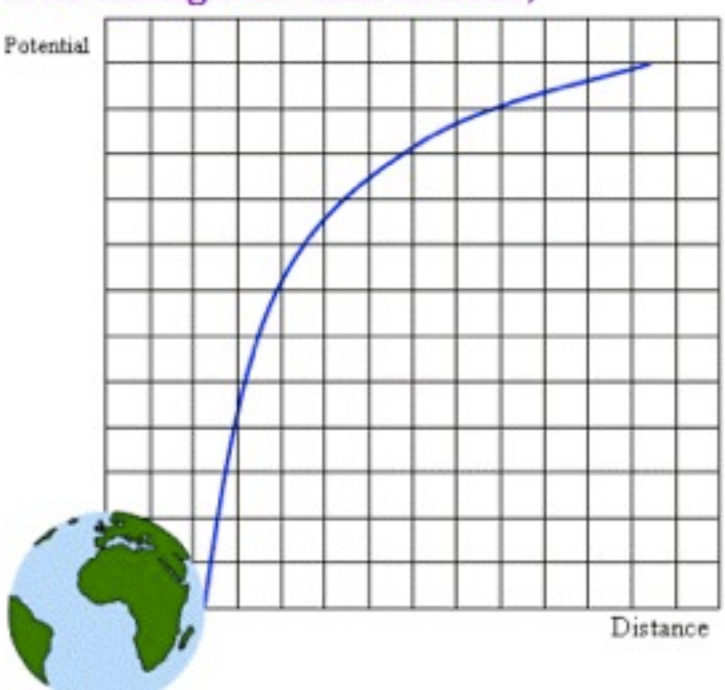
A picture like this labels what the magnetic field is at each point (it *means* how much force a little magnet *would feel* if it were sitting there; like how hot you *would feel* if you were in Texas)



The "gravitational field"

is just the potential energy you would have at each altitude

(Which means: the amount of kinetic energy you'd have when you hit the ground, after falling from that altitude)



Three possible solutions

1. Energy conservation is only true for local forces, not in general
2. There's a*nother* sort of energy – "potential" energy – which goes down while the kinetic energy of the falling ball increases.
3. The "gravitational field" is a real "thing," and has its own energy.

The Earth acts locally on the field, and the field acts locally on you, so kinetic energy is always conserved (but you need to count the field's kinetic energy too)

So: is there action at a distance?

- Is the field "real" or just book-keeping?
- Is kinetic energy really conserved?
- Is "potential energy" real, or is *it* just book-keeping?

Is energy always conserved?

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New forms of energy

- Kinetic energy
- Potential energy
- Sound
- Heat
- ... others?

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Levels of description

Questions...

(0) Was energy discovered, or invented?

(1) How can we have an energy shortage if energy is conserved?

(2) What is solar energy made of?