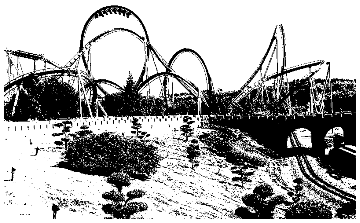
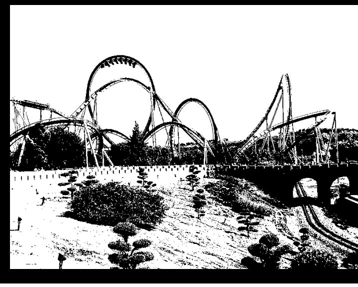
Energy, Power and Momentum



How does a roller-coaster work?



Energy

- an incredibly powerful idea, which governs the behaviour of
  - cars
  - humans
  - cell-phones
  - atoms
  - weather
  - galaxies ....

Start with the energy of motion

Kinetic energy

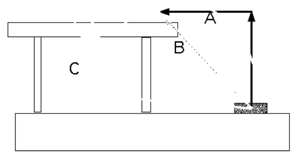
- is defined to be
- K.E. = $^1/_2mv^2$

Potential Energy

- If you drop something, kinetic energy increases.
- This energy is originally in the form of potential energy (P.E.).
- Near the earth's surface if you lift a body of mass m through a height h, its change in PE is
- P.E. = mgh

Note it doesn't matter how we get the energy

- e.g putting a block on a table can be done in many ways, but the energy is always the same



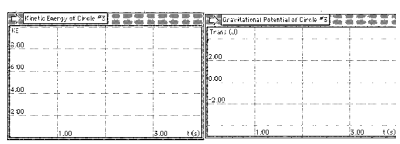
- Need a unit for energy: the Joule (Joule originated study of heat energy ⇔ mechanical energy)
- so a 1500 kg car travelling at 10 m/s has a KE of
- 1/2 mv² = 75000 J
- 1.5 kg computer dropped from 2 metres
- mgh~ 30J

Some conversions

- kilo: 1kJ = 1000 J
- mega: 1MJ = 10^6 J=1000000 J
- giga: 1GJ = 10^9 J=1000000000 J
- tera: 1TJ = 10^{12} J=1000000000000 J
- peta: 1PJ = 10^{15} J=1000000000000000 J
- eka: 1EJ = 10^{18} J=1000000000000000000 J

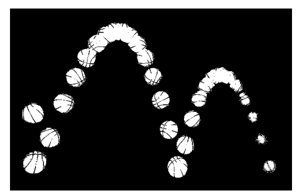
Conservation of Energy (nothing to do with energy conservation!)

- Energy can be transformed from one kind to another, but cannot be created or destroyed
- As long as there is no friction total (mechanical) energy will be conserved: it can be transformed from one form to another.
- P.E. ⇔ K.E.
- Doesn't matter how complicated the force is



Note that the force can be incredibly complicated

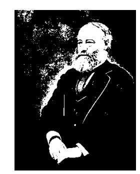
Most systems dissipate energy



- But actually it just gets converted to heat energy

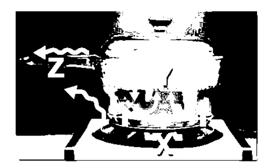
Heat energy

e.g boiling one litre of water (turning it to steam) takes ~ 2.3 MJ (million joules)



James Prescott Joule

Joule was the first person to figure that heat was a form of energy

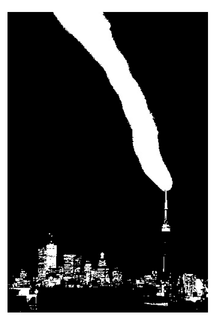


But we could get the energy from somewhere else...... e.g. Chemical energy

- Burning 1 Litre of gasoline ~35 MJ (35000000 J)

Electrical Energy

- Lightning bolt has about 5 GJ
- 5 billion joules



Nuclear Energy

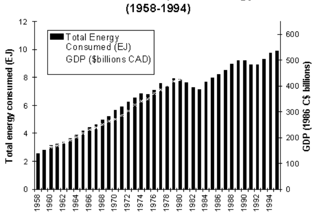
- Hydrogen bomb: heat small amount of gas up to ~10 billion °C for a very short time
- ~1 PJ
- 100 trillion Joules

Bio-chemical energies

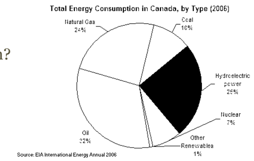
- Your daily consumption (as food)~10MJ

How much energy does Canada use?

- 1 EJ = 10^{18} J/year



- Where does it come from?



Residential 14%

Transportation 25%

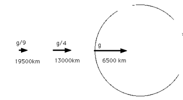
Commercial and Institutional (includes Pipelines) 14%

Industrial 47%

Where does it go?

Gravity again

- Since the force gets weaker as we move away from earth, expect P.E. to get smaller
- near Earth's surface
- P.E. = mgh
- anywhere:
-



- What are these?
-

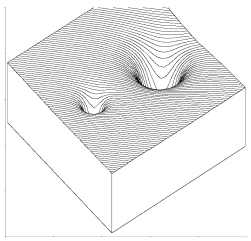
Mass of whatever we are looking at

Mass of Earth

Constant

Distance from the centre of the earth

- To get to moon, must escape the "gravity well" of the earth and fall into that of moon

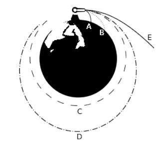


How fast do we need to throw something to escape from the earth's gravity?

- At the earth's surface, we want some K.E + some P.E.
-

Total energy never changes

- At an infinite distance from the earth, spaceship has stopped moving
- K.E. is zero
- P.E. is zero

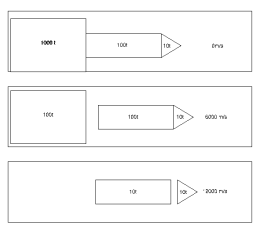


- e.g. for the earth:
- R = 6500 km = 6.5 x10^6 m
- G = 6.67x10^{-11}
- M= 6x10^{24} kg
- then
- V_{escape}~11100 m/s ~ 11 km/s
- V_{orbit}~7 km/s (close to earth's surface)

- Means there is a minimum energy we must have to escape earth:
- e.g. for 1kg need **at least** 60 megajoules (roughly 3 litres of gas)
- but the 3 litres of gas weighs more than a kilogram ......

This has been done with rockets

- How fast can a rocket go?
- Depends on exhaust speed.
- Suppose we have rocket with a mass of 100 tonnes, final mass 10 tonne, exhaust vel = 3000 m/s, final vel will be ~6000 m/s
- In practice need multi-stage rocket

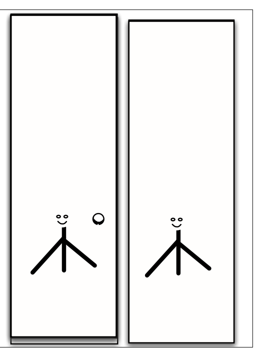


Space Shuttle Atlantis

Black Holes

- Invented by .....?
- Einstein
- Hawking?
- Well, actually, John Michell, rector of Thornhill Church in Yorkshire
- geologist?philosopher? astronomer? Seismologist?
- Polymath.
- presented his ideas to the Royal Society in London in 1783.

- A particle will escape from the earth if it has positive energy
- At the earth's surface, "escape velocity" is 11 km/s



- A particle will escape from the earth if it has positive energy
- At the earth's surface, v~ 11 km/s
- However we can interpret this differently: what radius would the earth have for a given escape velocity? In particular, if the escape velocity is the speed of light c, nothing can escape

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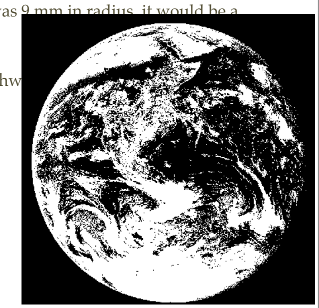
Black Holes

- This is the Schwarzchild radius (loosely the black-hole radius) for any mass.
- What is this for the earth?
- ~ 9 mm

(there are actually two factors of 2 error which cancel out.....weren't we lucky!)

- If the earth was 9 mm in radius, it would be a Black hole
- This is the Schw... hole radius



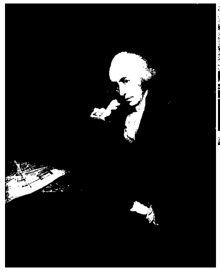
Peter Watson

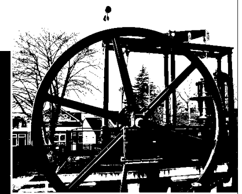
Energy ≠ Power (but they are related)

- Power = rate of energy consumption (or rate of energy production)
- 1 watt = 1 Joule/second
- Light-bulb ~100W
- You (from food) ~ 100 W
- Laptop~50 W
- Car (at 60 km/hr) ~ 40 kW
- From sun: 1.4 kW/m²

!

James Watt





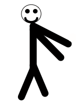
- Beam engine was first efficient steam engine
- enabled the industrial revolution

Canada

- Total ~300 GW
- Electrical ~60GW
- per capita ~ 10 kW
- Note (very confusingly) a kilo-watt hour is a unit of energy not power
- 1 kWh = 3600 x 1000 J = 3.6 MJ

One more related idea: Momentum

- Stopping a tennis ball is easy



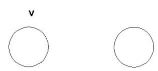
- Stopping a medicine ball isn't easy

- Momentum
- p = mv
- = mass ×velocity
- To stop an object requires
- force×time
- (can supply a large force for a short time, all small force for a long time)

- Note that (just like energy) total momentum is always conserved.
- Total momentum = 0

After the collision,
they may bounce back (if collision is elastic)
or both stop (if they are sticky)

Total momentum = mv
What happens?

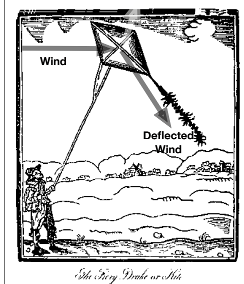


Hi Peter,

Bruce Deachman here again, with the Ottawa Citizen. I was wondering if you might be willing to help me with another story for my Days of Summer series. This time I have in mind to explain the physics of kite-flying. What keeps them up, how different shapes factor in, what the tail does, why the string, although taut, doesn't appear perfectly straight, that sort of thing.
What do you think? If you're willing, we could do it by phone if that's convenient.

thanks again, and I hope you're having a great summer,
Bruce

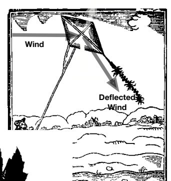
How many forces?



Lift force comes from change in momentum of air molecules

How many forces?

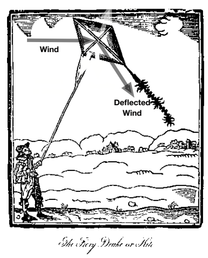
- Gravity and lift



Would just blow it across

How many forces?

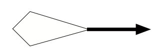
- Add in the tension in the string



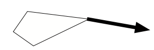
Forces will "balance out" (add to zero)

What does the tail do?

Tail is much heavier
Has more air resistance



If the kite swings to one side
The tail pulls it back
I.e. Provides stability



Why isn't the string straight?

No string is ever straight: gravity always pulls it down!

Day 4 explained the science of skipping stones; it turns out he knows a thing or two about kite aerodynamics, too.

So imagine first, a side-view picture of you flying your kite. The wind, essentially moving horizontally, hits the surface of the kite, which disrupts the momentum of the air molecules and deflects them downward. And if we learned anything in high school, it was surely Newton's third law of motion, which states that for every action there is always an equal and opposite reaction, and so the downward force of the wind creates an equal lifting force on the kite.

Next, you factor in gravity, which is always pulling the kite straight down. With just the lifting force and gravity, says Watson, you in essence have a blown leaf. "It would be lifted by the wind and it would be falling by gravity, as it gets blown across the garden.

"So now you've got the third force, which is the tension in the string, and according to Isaac, if you've got three balanced forces, the whole thing will stay in equilibrium, and the kite ideally will stay exactly where it is in the sky." (In a perfectly controlled environment, the kite would, in fact, remain motionless; try it the next time you're goofing around in your wind tunnel.)

But the reality, adds Watson, is that you'll always get turbulence at the kite's edges, similar to the swirling eddies created in the water when paddling a canoe. "You can't see them in air, but the same thing is happening around the edges of the kite, and that's why it flits from side to side.

Enter the kite's tail: With less lift acting on it, the tail largely remains in the same place when the kite is buffeted by the wind, and acts as a kind of anchor, pulling the kite back to where it was. "It's kind of a feedback mechanism. You yank the kite to one side and the tail responds more slowly, so the tail twists it back to where it was." That, too, explains why many kite tails have bows intermittently tied to them: to add weight and friction, thus increasing the tail's stabilizing effect.

As for the apparent curve it the kite's string, Watson says that it's not simply some illusion; it's gravity pulling the string earthward.

Next summer, we'll examine why fighting kites require two strings to manoeuvre, but that's enough for now. Time for recess.

bdeachman@ottawacitizen

Day 58: If apples fall, why do kites fly?

BY BRUCE DEACHMAN, OTTAWA CITIZEN AUGUST 16, 2013

Gillian Lister, 9, flies her kite in the skies high above Ottawa.
Photograph by: Bruce Deachman, Ottawa Citizen

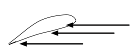
OTTAWA — You're in a large, open field, soft grass underfoot, the wind at your back. You're holding a wooden spool of string. At the other end, a kite dances in the breeze, mostly staying in one spot but now and then darting and weaving in ways over which you have no control.

How exactly does it stay up there, you wonder. What does the tail do? And why does the string, which you couldn't pull any tighter if you tried, appear curved?

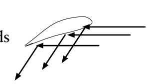
And so we return to Carleton University professor emeritus and physicist Dr. Peter Watson, who on

How do birds/planes fly?

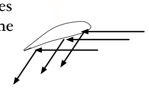
Air strikes the wing



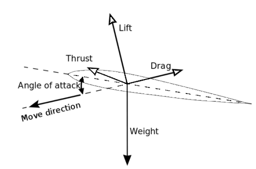
And is deflected downwards



Change in momentum produces a force which lifts the bird/plane

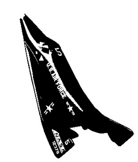


Reality is (a lot!) more complicated!

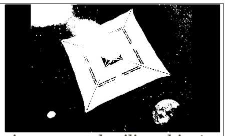


How about space craft?

- Two separate problems
- Flying through atmosphere requires wings to provide, lift
- Must reduce drag



- Flying through space:
- no drag, so any shape works



- so we can even think of radiation powered sailing ships!
- Need huge, very light sail: Say 1 km^2, 10 μ thick so very vulnerable to meteors etc
- Only works in space (so still need rocket to escape earth)
- acceleration very small (maybe g/1000)
- But wouldn't a solar sailing ship be romantic
- Small ones will be launched soon