26.09.08 science review: energy and power

https://elab.hpa.edu/apes/texts/fr3e/fr3e_ch2.pdf

Review:

- **energy always moves from high energy (e.g. hot) to low energy (cold), or ordered energy (banana) to disorder (heat)**
- **entropy is a measure of disorder, so Δuniverse > 0 (everything moves to disorder, including your room or closet)**
- **energy cannot be created, but can be converted, like a banana (chemical energy) to heat and motion (you running around)**
- **nothing is 100% efficient, so your banana only turns about 33% of its energy in to motion, most of it is waste heat**
- **same for your car: 9$ of gasoline buys you 3$ of motion, and 6$ of heat**
- **EVs are more efficient as they are not heat engines (hot moving to cold), and they capture motion in batteries for starting up again (regenerative braking)**
- **three rules of thermo (heat) dynamics (movement):**
  - **you can't win (nothing has > 100% efficiency)**
  - **you can't break even (all reactions have an energy tax as heat)**
  - **you can't get out of the game (all reactions tend towards disorder)**
- **energy moves in one of three ways:**
  - **radiation (heat lamps, light) can be reflected (foil) or absorbed (hot pavement)**
  - **conduction (contact) can be insulated (styrofoam) or conducted (copper pans)**
  - **convection (movement) like a convection oven (air in motion) or all weather**
- **temperature is based on the velocity of molecules**
- **even if the molecules are going fast, there must be enough of them to conduct heat, so high altitude planes release steam (burning kerosene) which freezes (jet trails)**
- **positive feedback: radiation heats the polar ice (white) melting it (darker) which absorbs more energy and melts more**

- **negative feedback: you run, get hot, sweat, cool down**
- **energy and mass systems can be open (energy comes in) or closed (mass stays the same)**
- **where these are balanced it is a "steady state"**
- **all weather is based on these concepts:**
  - **solar radiation heats the surface**
  - **the surface conducts heat to the air**
  - **warm air rises (less dense), along with water that has evaporated because of the heat energy**
  - **as the warm air rises, it cannot hold water, so it rains**
  - **cooler air descends to the surface to be heated again**
  - **where air rises, it rains (e.g. Seattle)**
  - **where air falls, it is a desert (e.g. Sahara)**
  - **air motion on our planet is divided into three cells: Hadley, Ferrel, and Polar**
- **hurricanes are a good example of a heat engine**
  - **shaped like a huge smokestack**
  - **hot air rises, condensation forms rain**
  - **as a small storm gets big (100km across) one part is closer to the equator (faster) then the other (slower, north in our hemisphere)**
  - **coriolis is the spinning of the hurricane, ccw in our hemisphere cw in the southern hemisphere**
  - **as the air rises it pulls in more air, like a skater pulling arms, spinning faster**
  - **hurricane "eye" is smallest for dangerous hurricanes**
  - **tornadoes also spin, but for smaller scale reasons, vertical updrafts and downdrafts in huge storms**
- **Reaction rates:**
  - Every 10°C increase in temperature doubles the speed of any reaction
  - Who cares?
  - When you have a fever, you burn fuel much faster
  - When explosives heat up, their blast is much more violent

Energy:

- same as work
- don't care if it happens fast or slow, just lift the rocks
- minilab: calculate your mass in kg (lbs x 2.2)
- how high are the stairs? (meters)
- lifting your mass up the stairs is WORK: PE = mgh. (gravity is about 10 here)
- how much work did you do walking up the stairs?
- important: not how FAST you do it, just how MUCH you did

- work=energy, how fast the work is done= power

Power:

- power is how FAST you do the work
- athletes need the ability to do work (lifting) as well as quickly (power)
- https://www.youtube.com/watch?v=S4O5voOCqAQ&t=178s
- walk up the stairs, as slowly as you like
- calculate the work you did walking up the stairs: mass x 10 x height (meters)
- units will be in Joules (energy)
- next, run up the stairs and time yourself
- work/time is power in Watts (Joules/second)
- 747 Watts is one horsepower
- how many Watts and hp can you produce?
- how does it compare to Robert Forstmann?
- what is the difference between your slow power and your fast power?

Electrical work and power:

- 1 Watt is the same as 1 joule (work) done in one second (time)
- 1000 Watts is one kilowatt (kW)
- a hot water heater uses energy (does work) at a certain rate (power), measure this in Watts and kW (1000 Watts)
- if it runs for one second, the power number (joules/second) is the same value as the energy (joules)
- to calculate energy used to heat the water, multiply power (Watts or j/s) x time (seconds)
- you will see this on the AP exam, here's what it may look like:

Sample AP problem:
Your home hot water heater converts electrical energy into heat energy at the rate of 4500W.

1. how many kW is this?
2. if it runs for 2 hours each day, how many seconds is this?
3. how many joules is this?
4. calculate how many kWh this is (kW x hours)
5. convert this to joules, are your answers the same?
6. if one kWh costs your family 40 cents ($0.40), how much does this cost each day?
7. each month?
8. each year?
9. how could you reduce this?
10. why does the electric company charge you for kWh not kW?
11. why don't they use joules like the rest of the world?

Module 5 Energy flows, feedback

- energy terms: cal, kcal, Joule, kWh, BTU

- power terms: Watt, J/s, hp
- EM spectrum
- KE= 1/2mv^2 or 3/2kT (T is degrees Kelvin)
- PE = chemical bonds or mgh (height potential energy)
- ICE vs. hybrid vs. electric cars
- thermo 1: conservation
- thermo 2: efficiency
- thermo 3: entropy
- open and closed systems
- equilibrium, stability and steady states
- positive feedback loops
- negative feedback loops

Energy terms:

Energy is the ability to do work

You may have seen this in other science courses as force x distance, PE=mgh, or other descriptions

We use the following units for energy:

- calories: the energy used to heat 1 gram of water 1 degree C (note small c)
- kcal: one thousand calories
- Cal: a single food calorie, equal to 1000 chemical calories (note big C)
- Joule: the work needed to move something 1 meter against a 1 Newton force (note caps for dead people)
- 1 cal = 4.18 Joules (good to know)
- kWh = one kiloWatt of power used for 1 hour (heating tea for an hour, costs about $0.40 here)
- BTU: British thermal unit, most often seen in heating, ventilation and cooling (HVAC) systems

Demo: walk up stairs

Power:

- Energy is the ability to do work, or to measure work that is done.
- Power is how FAST that work was done, measured in Watts (note caps again, another dead person)
- You could walk up a flight of stairs, doing some amount of work:
- 50 kg person, 10 m stairs, g = 10, equals 5000 Joules
- If you do this in 100 seconds, you have done this with 50 Watts of power (50 joules/second)
- If you did it in 10 seconds, you would be creating 500 Watts of power (that's a lot)

- 1 horsepower (hp) is 747 Watts
- Fun fact: some elite cyclists can create over 1000 Watts for many minutes-true animals
- Another fun fact: the electric company does not care how fast you use energy (kiloWatts), they only care how many hours you used this power (kWh)
- Think of water: you are not charged for how FAST you use the water, just how MUCH you use

https://www.youtube.com/watch?v=S4O5voOCqAQ&t=178s
Demo: run up stairs

Electromagnetic spectrum:

Spectrum means a spread of values, so a musical spectrum might mean the lowest and highest notes you could sing or hear.

The electromagnetic (EM) spectrum describes EM radiation, that includes in order of increasing energy:

- radio waves: (radios use these)
- heat (IR or infrared): snakes can see these, also heat lamps over food or for people
- visible light: you can see these: ROYGBIV
- UV (ultraviolet) light: bees can see these, they also burn your skin
- X-rays: films and sensors can see these, they go through your skin, but less so through your bones
- gamma rays: go through most stuff (remember?), mutate DNA
- and cosmic rays: mysterious stuff, comes from supernova explosions, can form muons (cow rays)
- if you see Tiffany, ask her about relativistic muons...

Demo: spectrographs

The visible spectrum includes the following colors, in order of energy:

Low energy-------

- red
- orange
- yellow
- green
- blue
- indigo
- violet

High energy------

You can now see why infrared is below red, and ultraviolet is above violet

Plant pigments have evolved to resonate with certain colors, like chlorophyll likes green light, others like reds and so on.

Fun fact: autumn leaves are red because the green is gone (winter, darker). The red was there all along.

Kinetic energy:

- When you ask a physicist (I am one, so I know) about Kinetic energy, they will drone on about moving objects, their mass and velocity...
- KE = 1/2mv^2
- This is incredibly fascinating you will agree (?) and it explains why car crashes at 80 mph are 4x more damaging than ones at 40 mph...
- In chemistry, we use KE to describe the energy of moving molecules: KE = 3/2kT, where T is the absolute temperature (Kelvin)
- This means that if you double the Kelvin temperature, you double the KE of a molecule.
- This changes for different molecule shapes (3 comes from x, y, z motion), which you may find interesting if you study physical chemistry (ask Dr. J)
- For our purposes, we need to know that increasing temperature increases the speed of molecules:
- 3/2kT = 1/2mv^2
- So, those physics guys were not crazy.
- This has huge implications on climate change, phase changes, rain, condensation, and many other things.

Potential energy:

- If you ask a physicist (what, again?) about potential energy, they will blather on about mass, gravity and height.
- While scintillating, this is useless in most chemical equations, which tend to happen at the same height.
- It does, however impact some weather phenomena, so let's let them have this one.
- If you ask a chemist about PE, they will often refer to chemical bonds, which represent energy stored like a spring holding molecules together
- If you ask a nutritionist about PE, they will talk about Caloric content (food)
- If you ask a coach about PE, they will tell you about the untapped potential of an athlete...maybe
- In APES, we mainly care about stored energy, usually in a phase change (latent heat of vaporization) or chemical bonds like in food.

Demo: springs

ICE, hybrid and electric cars:

- ICE stands for internal combustion engine (e.g. normal cars, lots of heat, hot brakes etc.)
- hybrid cars capture the KE of motion and store it in batteries to accelerate the car, saving energy
- electric cars do this as well, but have no thermal engine parts like ICE or hybrid cars, so they are much more efficient
- electric cars capture braking kinetic energy and store it as chemical energy in batteries (often lithium)

Demo: Prius, Tesla

Thermodynamics: one two and three

Thermodynamics is the study of heat (thermo) in motion (dynamics)

There are three big laws of thermodynamics:

1. you cannot create or destroy energy (you can't do this with mass either, more on this later)
2. in any reaction, there is an energy "tax" you could think of as friction
3. all reactions go naturally towards disorder

Short Las Vegas version:
1. you can't win
2. you can't break even
3. you can't get out of the game

- You can imagine a magical car that you put 1000J of energy in the tank and 2000J of work is done by the engine.
- No
- Way.
- The most efficient Formula one racing car engine is about 45% efficient.
- Where does the rest go?
- Heat.
- Your body is at most 33% efficient in turning M&Ms into work. The rest?
- Heat.
- One way of looking at disorder is **entropy**, a measure of disorder.
- You can imagine a pool table, hitting the triangle of balls and then spreading across the table.
- It is more likely to go in this direction (more disorder) than to have the balls spontaneously jump out of the pockets and form a perfect triangle.
- Not to get depressing, but there is a formula that goes like this:
- ΔS for the universe is >0 translation: the universe always moves towards disorder

- so sad...

Demo: look up thermal efficiency of formula one cars, diesel and EV

Open and closed systems:

- This means different things to different folks, but you could imagine a system where mass and energy are contained in the system as closed.
- You might also look at a system where certain nutrients are recycled as closed.
- You could look at recycling paper as a closed system to a degree.
- Most of our product cycles are open: we throw stuff away instead of recycling.
- Much more on this later...

Equilibrium, stability and steady states:

- Equilibrium means literally "equal freedom" , in this case equal freedom to move from one condition to another.
- Imagine two fish tanks with a pipe connecting them.
- Fish are free to move from one to the other.
- Not the same fish, but about the same fish on each side.
- This is equilibrium.
- Stable systems are ones where equilibrium exists, and can recover from stresses (resilience)
- Steady state systems are ones where the inputs equal the outputs, and are usually stable as well.
- Unstable systems have nasty feedback loops (see below)

Positive feedback loops:

- In a positive feedback loop, any change causes a greater change as a result
- Boat example: if a large cruise ship tilts over, the mass of the people on the ship make the ship want to tilt more.
- Climate change example: as the planet warms, ice sheets melt, changing from reflective ice to darker ocean water that absorbs more heat, melting more ice.

- Permafrost example: as the planet warms, the permafrost melts, releasing methane gas, which is a greenhouse gas, causing more warming, and more methane...
- Positive feedback loops exist in your body as well: massive blood loss and childbirth are two examples.

Demo: look up femoral artery hemorrhage

Negative feedback loops:

- Where positive feedback tends towards instability, negative feedback loops restore stability, and naturally recover to initial conditions.
- As you exercise, your body sweats, cooling the body.
- This is a negative feedback loop.
- Some coast guard rescue boats are created with negative feedback as well: the more they tip over, the more they want to come back to normal.
- Psychologists often use these terms to describe personalities and relationships...

Demo: sailing ships, keel

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