Thermal Energy

Heat and Temperature

Clickers Channel D

NO MID-TERM

- in this course.

Mathematica

- Optional (but very powerful) software for doing maths and substituting numbers into equations.
- Also good mathematical word processor
- Free to install for ANU students enrolled in a science course - see Wattle page

CPR news

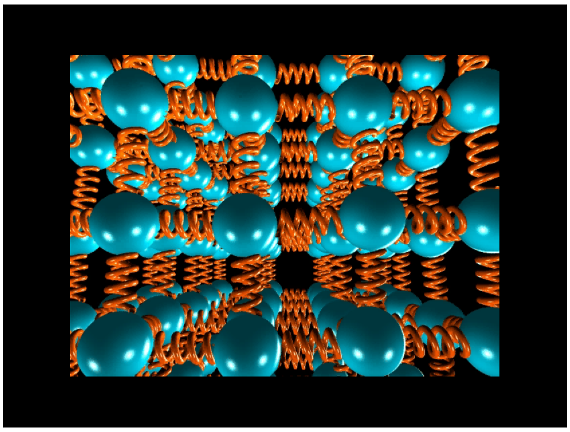
- A few people posted their work incorrectly.
- E-mail me if you have one of these to mark.
- I wil contact the person who posted it.

Power

- One definition I forgot to give earlier - energy per unit time is called POWER and measured in Watts.
- One Watt is a Joule per second.

How energy can enter or leave a system

- We've talked about one way (doing work on a system).
- Here is another way - heat transfer.
- But what is heat?



Heat is a form of energy

- In a solid it's actually a combination (roughly 50/50) of kinetic energy in vibrating atoms and potential energy in the chemical bonds (which behave like springs) which hold them together.
- In liquids it is a combination of the kinetic energy and rotational energy of molecules.
- It's impossible to keep track of every bond and atom, so we lump it all together as "heat".

Fast

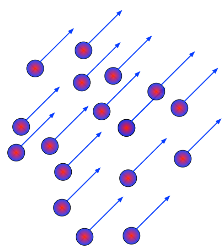
- How fast do you think atoms and molecules move, due to this thermal motion?

Fast

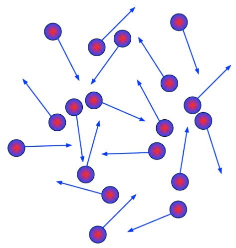
- For a typical air molecule at room temperature, the speed is around 16 m/s (60 km/hr).
- They don't get very far - they bump into other atoms in a tiny fraction of a micron and change direction.
- Similar speeds apply for the thermal motion of atoms in a solid or liquid.

It's really kinetic and spring energy

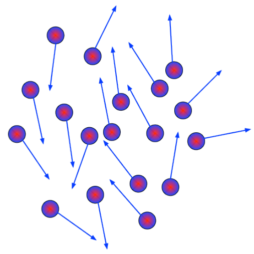
- Atoms moving around, chemical bonds (which act like springs) compressed or extended.
- If the motions in an object are aligned, we call it motion (kinetic energy), if they are random we call it heat.
- Most objects will have both!



This would be called bulk motion - you' d work out the kinetic energy.



This would be called heat - you' d work out the thermal energy



This is a confusing intermediate state. It is called turbulence and is really hard to model.

Kolmogorov Cascade

- Bulk motions in fluids tend to break up into smaller eddies.
- Which break up into smaller turbulent motions.
- Which end up as random motion of individual atoms - also known as heat!

Heat and Temperature

- If you add heat to something, its temperature increases.
- How much it increases depends on how big it is and what it's made of.

Which has more heat?

1. A kettle of boiling water.
2. Lake Burley Griffin in winter.
3. Not enough information provided.

Lake Burley Griffin…

- If the kettle had more heat, pouring it into the lake would make the lake really hot.
- In fact, because the lake (though cold) is vastly larger, it actually has much more thermal energy.

Equation

$$\Delta E_{\text{thermal}} = mC\Delta T$$

- where $\Delta E_{\text{thermal}}$ is the change in the thermal energy of a system, *m* its mass, *C* its specific heat capacity and ΔT the temperature change.
- You look up specific heat capacities for different materials.

Very substantial

- Consider a 160g cricket ball. Bowled at world record speed (around 40 m/s).
- Kinetic energy is $KE = \frac{1}{2}mv^2 = 128J$
- Warm it up by 1 degree in your hand and energy increases by

$$\Delta E_{\text{thermal}} = mC\Delta T = 0.16 \times 2050 \times 1 = 328J$$

So the thermal energy from even a 1 degree increase in temperature has double the energy of the world's fastest bowlers!

Example

- You dive from a height of 10 metres into a swimming pool.
- How much does this heat the pool up by?

Energy

- Your initial potential energy turns to kinetic energy.
- But then when you hit the water, it turns into water motions which rapidly end up as heat.

Solution

Initial (potential) energy: $m_{\text{diver}}gh$

Final (thermal) increase in energy: $m_{\text{pool}}C_{\text{water}}\Delta T$

$$\Delta T = \frac{m_{\text{diver}}gh}{m_{\text{pool}}C_{\text{water}}}$$

which will be very small...

(You'll probably heat the pool up a lot more by conduction of body heat while you swim to the edge)

Does adding heat always increase temperature?

Answer

- Not necessarily - if you heat up a mixture of ice and water, the energy goes into breaking the chemical bonds in the ice (latent heat) and until the ice has entirely melted, the temperature will not rise.

How does heat move around?

Huge topic - especially in engineering.

- Heat moves from hot to cold.
- Three main methods -
  - Conduction
  - Convection
  - Radiation

Conduction

- If atoms in one part of an object are vibrating more than those in another, the vibrations tend to spread until all atoms are vibrating equally.
- Some materials are good conductors (especially metals, where the free electrons carry the thermal energy rapidly from one place to another). Others (typically those with internal cavities) are poor conductors.

Equation

- The bigger the temperature difference across an insulator, the more heat flows.
- For a slab of insulator, with one (uniform) temperature on one side and a different one on the other, the heat passing though per unit time is:

$$\Delta E_{\text{thermal}} = \frac{A\Delta T}{R}$$

where the A is the area of the insulator and the R-value is a measure of the thermal resistance - you typically see the R value listed on insulation products.

For example

- An un-insulated house roof has an R-value of around 0.5.
- How much energy will you lose during a typical Canberra winter night, with an outside temperature of 0°C, an inside temperature of 20°C, from a 100 square metre house?

$$\Delta E_{\text{thermal}} = \frac{A\Delta T}{R} = \frac{100 \times 20}{0.5} = 4000W$$

So you lose 4 kilo-watts every second

kWh

- Energy is often measured in Kilo-Watt Hours, which is what you get from a power of 1000 W for an hour - i.e. 1000x60x60 = 3,600,000 J.
- During a 14 hour winter night, this means the house loses 4000x60x60x14 = 200 MJ = 56 kWh.
- Which at current electricity prices of 14c per kWh (ACTEW) is about $8.

Heater location

- To minimise heat loss from a room, where should you put the heater?

1. Near the window
2. Far away from the window
3. It doesn't make any difference.

Far from the window

- The heat loss through the window is typically much more than that through the walls.
- Putting the heater near the window will make it hotter there and hence increase the heat flow through the window.
- But in fact, architects usually do put heaters under windows. Why?

Uniform temperature…

- It's to try and even out the temperature across the room. So you don't get hot at one end and frozen at the other.

Wood and Metal

Imagine you put a block of wood and an equal sized shiny block of metal outside in the sun for a few hours on a hot summers day.

Which will be hotter?

1. The wood
2. The metal
3. Same temperature

Which is really hotter?

- If there was no sunlight, both would end up at the same temperature as the outside air.
- Sunlight adds more heat to the wood than to the metal because the metal is shiny and reflects most of it.
- But we all know metal feels hotter. Why?

Why does the metal feel hotter?

- When you touch something, you are really feeling the temperature of the receptors in your fingers.
- Because metal is a good conductor, lots of heat can flow from the hot metal into your fingers, making the receptors hot. It's large heat capacity also means there is plenty of heat to flow.
- But because wood is a poor conductor, most of the heat cannot flow into your finger - you are only affected by a very thin surface layer.

So -

- Remember that when you measure a temperature (either by touch or a thermometer) you are actually measuring the temperature of your measuring device.
- If heat transfer is poor, that may not be representative of the surroundings.

Convection

- In a fluid.
- Fluid gets hot, rises and transports the heat to colder areas.
- Usually very effective at transporting heat - dominates conduction in most situations on Earth, unless something (like a window) prevents fluid flow.

Usually rather complicated to calculate

- Crudely speaking the rate of convection is proportional to the square or even the cube of the temperature difference, but it depends heavily on the geometry of the fluid and whether it can flow freely, and whether there is a current/wind in the fluid in addition to the convection.

Is space hot or cold?

- The average temperature of the Earth is about 300 K.
- What is the average temperature of outer space near the Earth?

1. Much more than 300 K
2. A little more than 300 K
3. Close to 300 K
4. A little less than 300 K
5. Much less than 300 K
6. Not a meaningful question

It's actually very hot - over a million degrees.

- Which is to say that the few atoms up there are moving really fast.
- But would it feel hot?
- The density is so low that those few atoms would take an enormous time to heat you up.
- It's like being in a vast thermos flask - no significant conduction or convection in or out.
- In practice, your temperature would be controlled by radiation.

Flame

- You can feel something similar if you quickly wave your hand through a flame - you won't even feel the heat.
- The flame is hot (typically around 1000 K) but the density of air is low, so not much of it is conducted into your hand in the brief time interval.

Radiation

- Jiggling atoms in a hot region emit electromagnetic waves which carry energy away.
- If you are hit by electromagnetic waves they can cause your atoms to jiggle, warming you up.

How much you radiate..

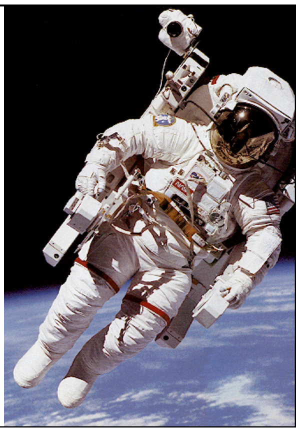
- The heat radiated Q is given by the Stefan-Boltzman equation:

$$Q = \varepsilon A \sigma T^4$$

where A is the surface area, T the temperature, ε the emissivity (typically 0.2-1.0) and σ the Stefan-Boltzman constant 5.67×10^{-8} J m^{-2} K^{-4}.

Hot in space?

- It depends on how much heat is released (from astronaut activity, power systems etc), but much sunlight is absorbed and how much energy is radiated.

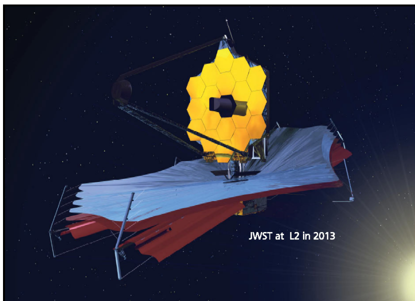


Too hot?

- It's very easy for astronauts to overheat.
- There are lots of power sources on spacecraft, and they are exposed to lots of solar energy.
- Engineers typically cover the spacecraft in shiny coatings to minimise solar radiation received, and build radiators in to get rid of excess heat (on the insides of the cargo bay doors on the space-shuttle, for example).
- Otherwise astronauts will boil in their own heat.

Too cold?

- On the other hand, if you design a spacecraft to radiate all the heat it normally generates and something goes wrong (i.e. Apollo 13) it can get very cold indeed…



- The James Webb Space Telescope uses a multi-layer sun-screen to block incoming solar radiation. Outgoing radiation from the back should cool it to below 50 K - allowing it to make extraordinarily sensitive measurements.

Bushfire

Radiation

- Was how most of the damage at Mt Stromlo was done.
- Radiant heat from burning trees came through the windows and added so much heat to things like the papers on peoples desks that they caught fire.

Heat and iteration

- If you want to compute how the temperature of something changes - you can use iteration.
- The heat flow in and out will depend on the temperature.
- And as heat flows in or out the temperature will rise or fall.

- Time becomes $t+\Delta t$
- Heat flow Q depends on temperature T
- Temperature increases by $Q\ \Delta t/HC$
- Where HC is the total heat capacity - the mass times specific heat capacity of everything in the system.

Summary

- Heat can flow in different ways: conduction, convection and radiation.
- How hot something feels may not be a reliable measure of its real temperature, depending on how easily heat flows between the something and your hand/ thermometer.