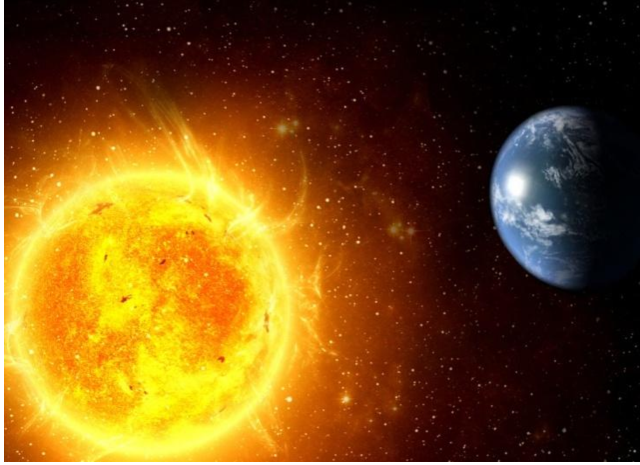
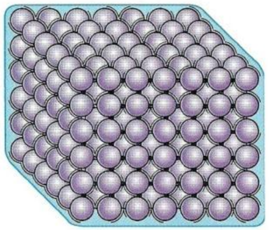
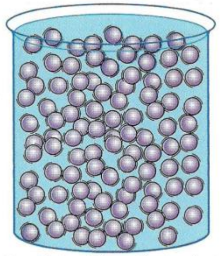


$$E = \frac{1}{2} m v^2$$

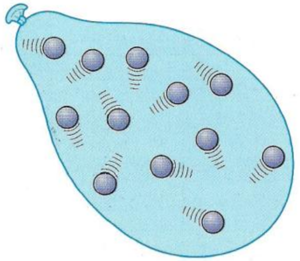
Energy & Heat



Solid Particles vibrate about fixed positions.



Liquid Particles vibrate, but can change positions.



Gas Particles move about freely.

Universe by Numbers: Day 3

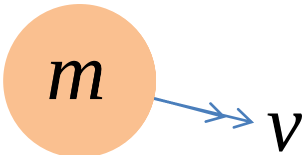
July 2016

Dr Andrew French

Kinetic Energy

$$E = \frac{1}{2}mv^2$$

Energy / Joules — Mass — Speed



$$m = 715{,}000\text{kg}$$

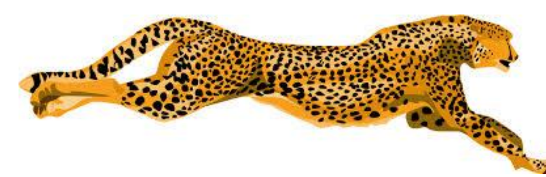
$$v = 75\text{ms}^{-1}$$

$$E = 2\times10^{9}\text{J}$$

$$m = 70\text{kg}$$

$$v = 8\text{ms}^{-1}$$

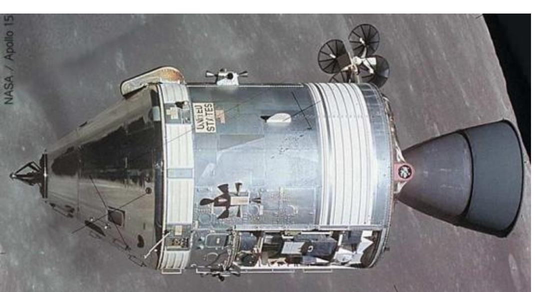
$$E = 2240\text{J}$$



$$m = 70\text{kg}$$

$$v = 31\text{ms}^{-1}$$

$$E = 33{,}600\text{J}$$

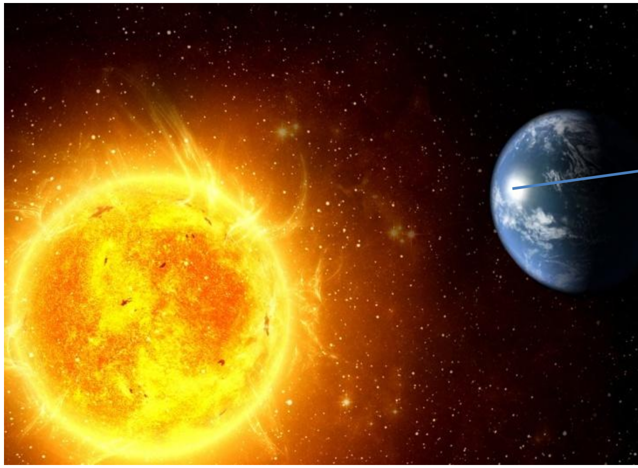


$$m = 14{,}690\text{kg}$$

$$v = 11{,}082\text{ms}^{-1}$$

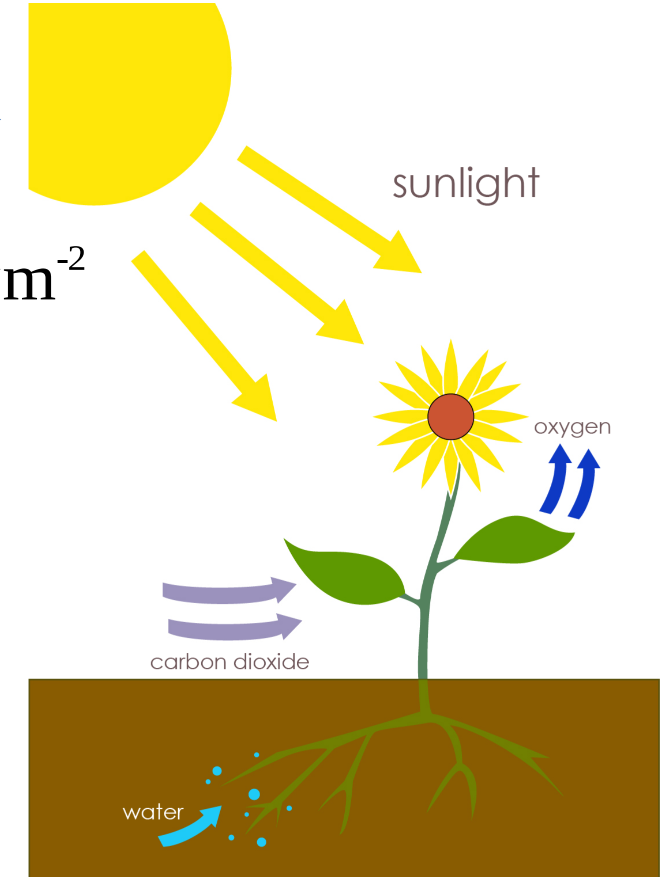
$$E = 9\times10^{11}\text{J}$$

A fundamental law of Physics is that of **conservation of energy.** Energy *cannot* be created or destroyed, merely converted into other forms



$3.8\times10^{26}\,\mathrm{Js^{-1}}$

$1.4\times10^{3}\,\mathrm{Js^{-1}m^{-2}}$



Photosynthesis

$1.7\times10^{7}\,\mathrm{Jkg^{-1}}$

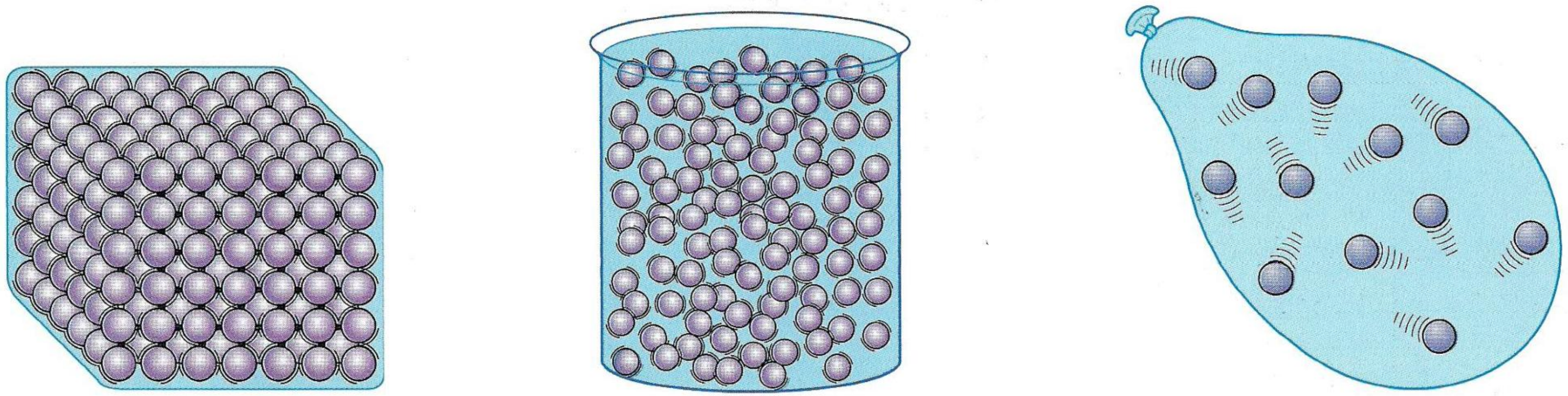
17kJ per g

$10^{7}\,\mathrm{J/day}$

Suggested calorie intake (Adult Male)

$1\mathrm{kcal} = 4184\mathrm{J}$

Kinetic theory: matter consists of tiny particles which are constantly in motion.
They attract each other when close, but this force weakens if they move further apart.
They *repel* if they get *really* close!

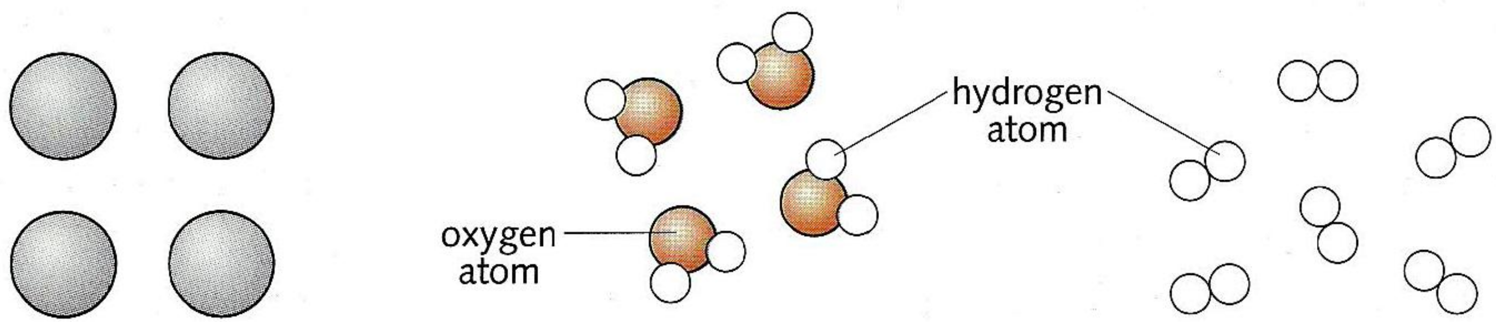


Solid Particles vibrate about fixed positions.

Liquid Particles vibrate, but can change positions.

Gas Particles move about freely.

Phases of matter: Solid, Liquid or Gas ← PhET



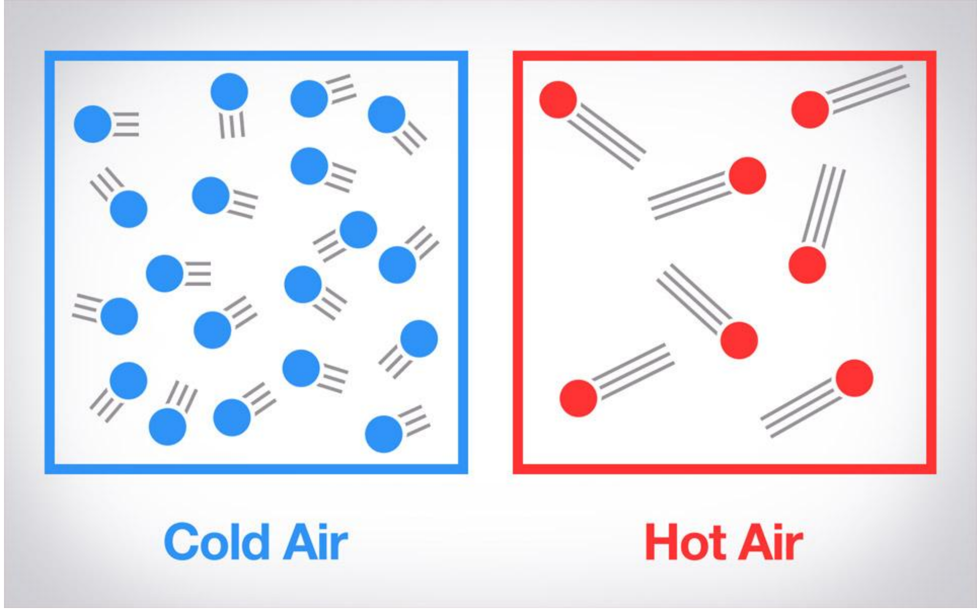
Iron atoms **Water molecules** **Hydrogen molecules**

Heat is the **energy** that we have to put into a material to warm it up.

Temperature is a measure of the ***average kinetic energy of each molecule***

The total energy (or ‘internal energy’) of the molecule is the **kinetic energy** plus the **potential energy of bonds** formed with nearby molecules

Inter-molecular bonds will be strongest in a solid, weakest in a gas



One **mole** of gas contains 6×10^{23} molecules!
12g of Carbon is one mole

So we talk about *average* energy

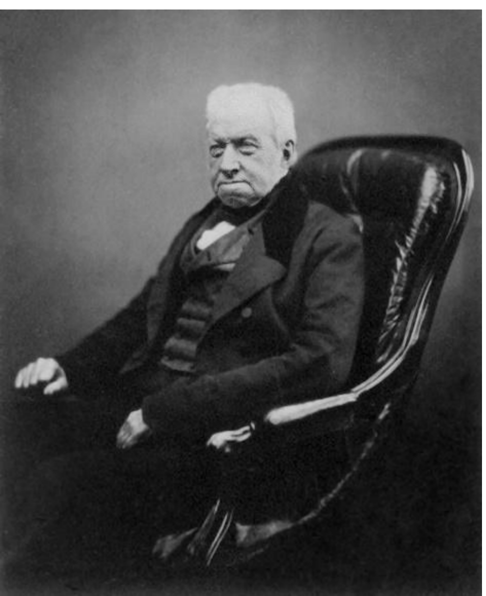
How *hot* something feels is more related to *heat that can be transferred from it rather than temperature*. A dense gas will therefore feel hotter than a low density gas at the same temperature, since more molecules will collide with your hand per second (and therefore transfer their energy) when the gas is more dense.

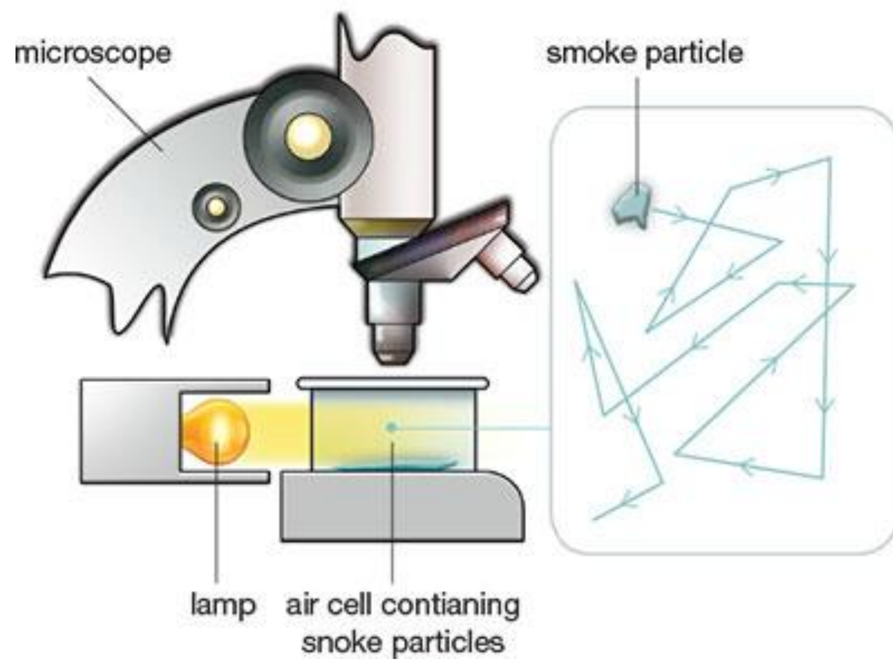
Temperature is not the same as heat. For example, a spoonful of boiling water has exactly the same temperature (100 °C) as a saucepanful of boiling water, but you could get far less thermal energy (heat) from it.

Brownian Motion is named after Robert Brown, who investigated the seemingly random motion of pollen grains in water.

The motion is a motivation for the **kinetic theory**, that is the zig-zag movement of the grains (or indeed smoke particles in the experiment described below) is caused by the random jostling of *smaller*, *unseen*, **molecules**. e.g. which comprise water, air etc.

Robert Brown
1773 -1858



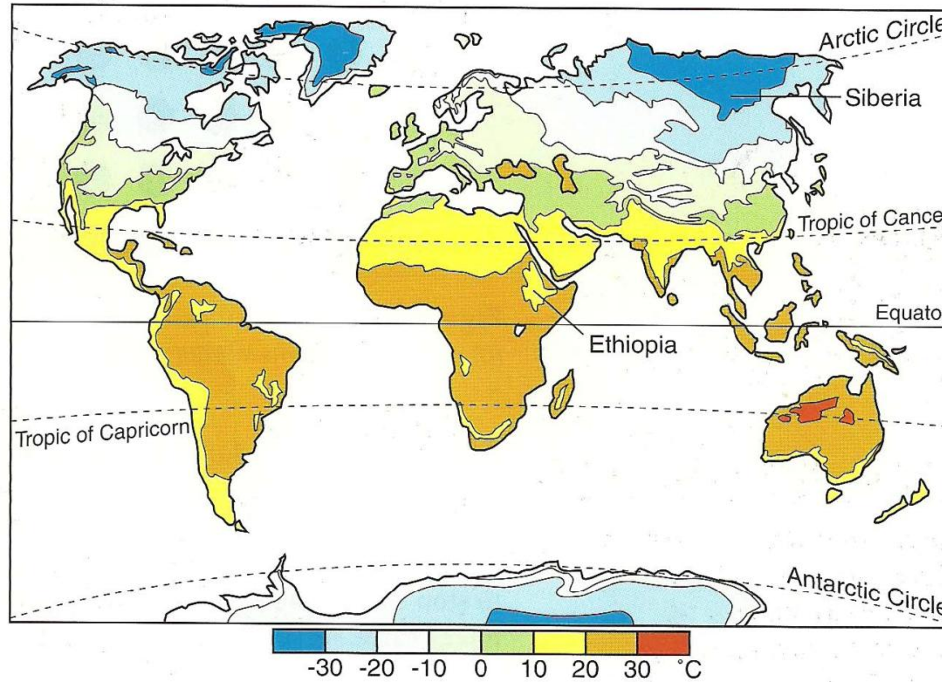


http://www.igcsephysics.com/sample/thermal_physics/page86.html

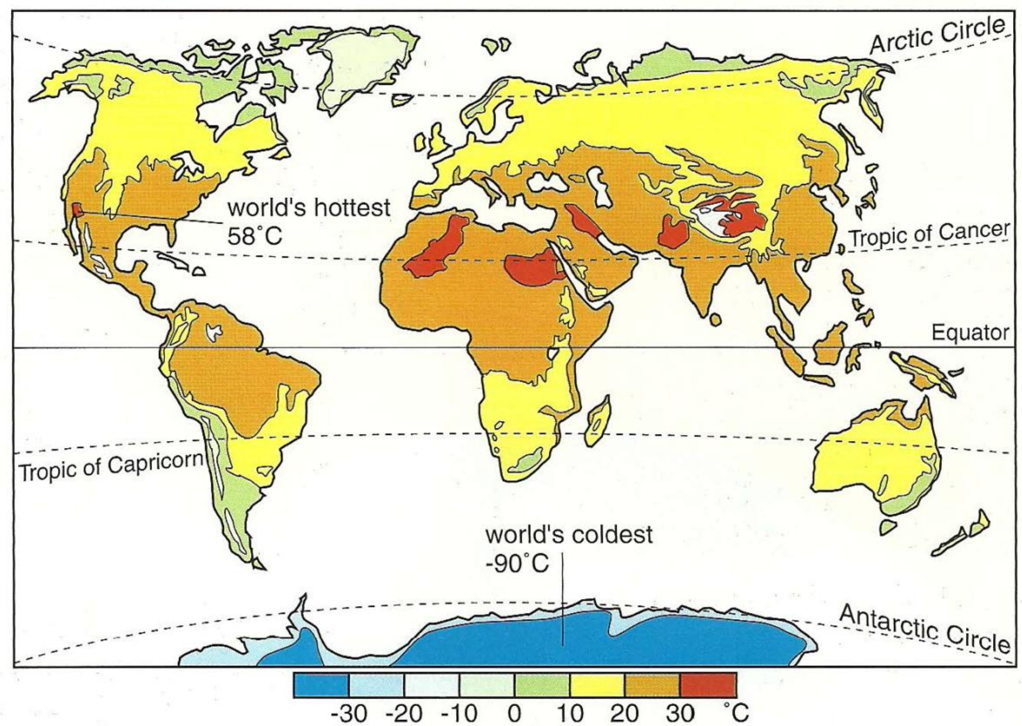
One **mole** of gas contains 6×10^{23} molecules! The complexity of such a vast number of collisions is why random motion is observed.

Sun's centre	15 000 000 °C
Sun's surface	6000 °C
bulb filament	2500 °C
bunsen flame	1500 °C
boiling water	100 °C
human body	37 °C
warm room	20 °C
melting ice	0 °C
food in freezer	−18 °C
liquid oxygen	−180 °C
absolute zero	−273 °C

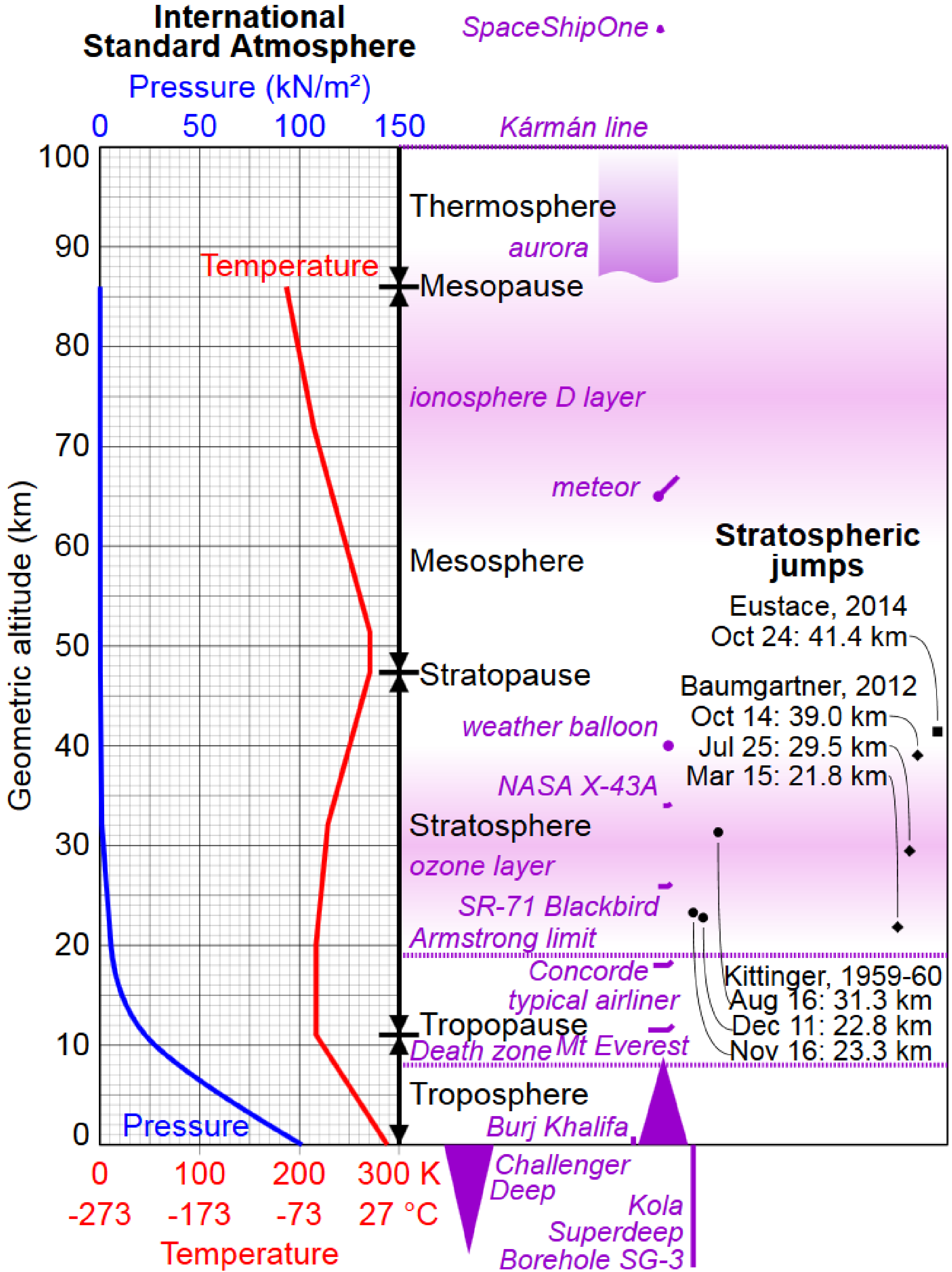
Jan

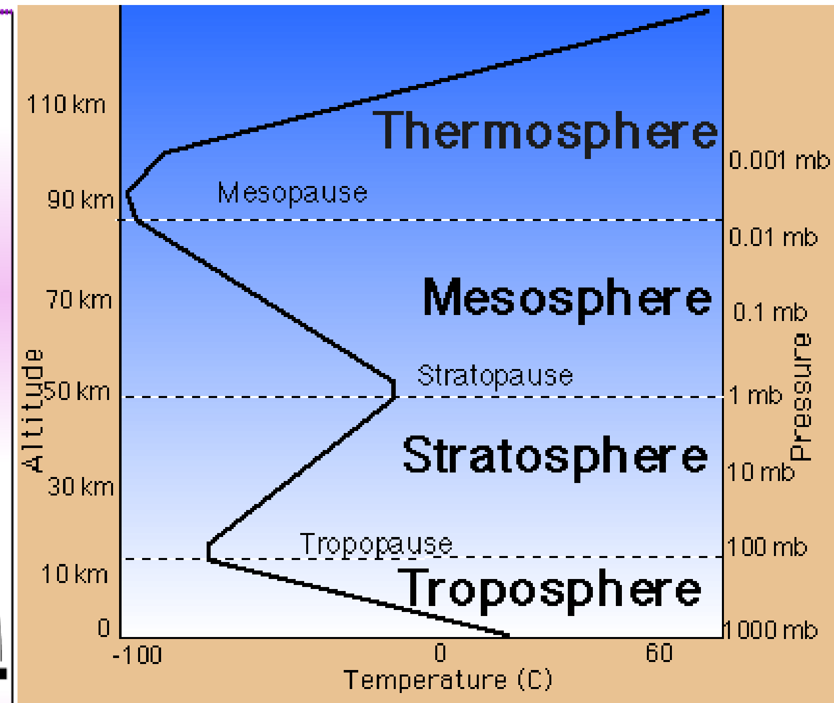


July

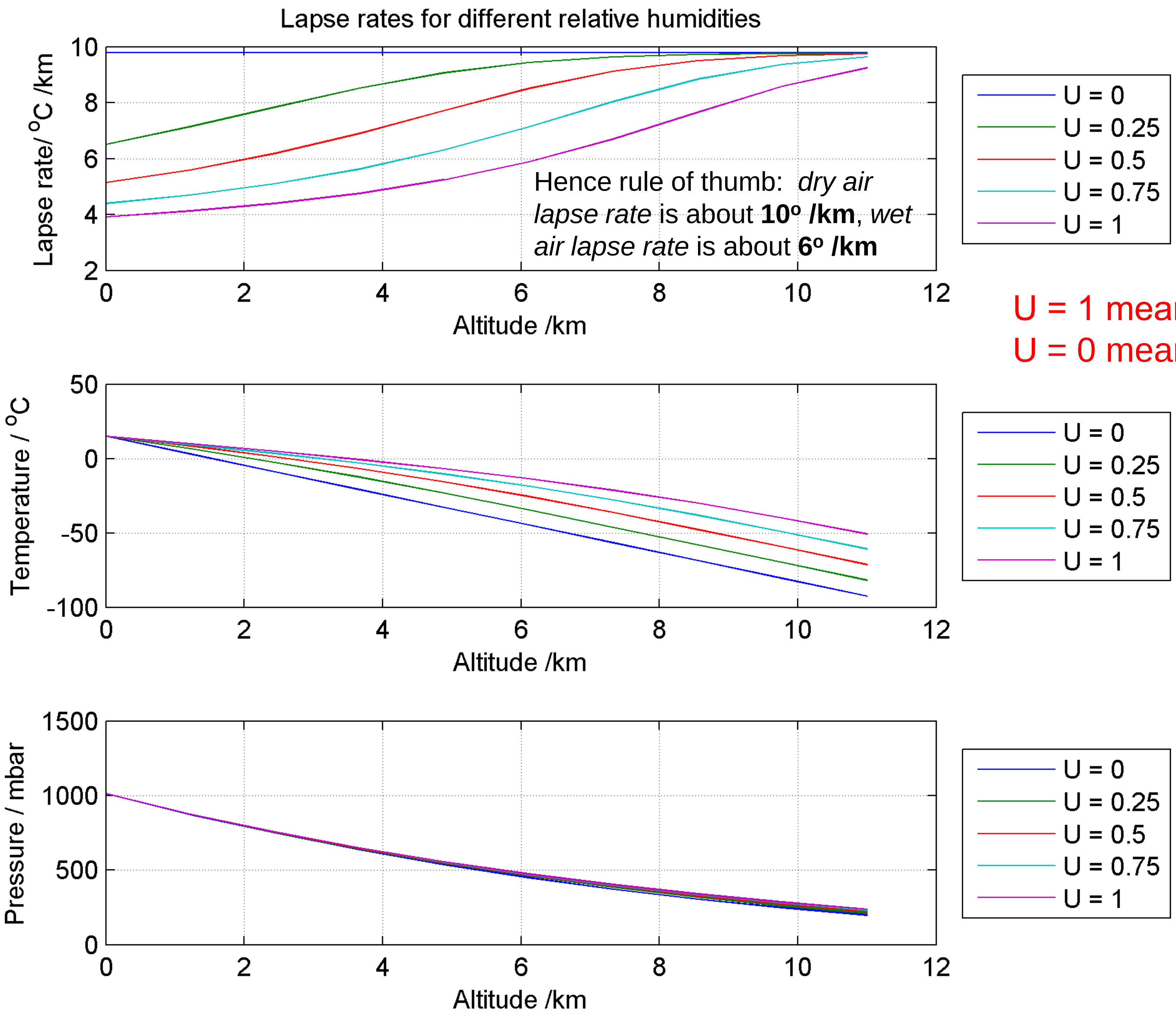


Temperature – the average energy of molecules

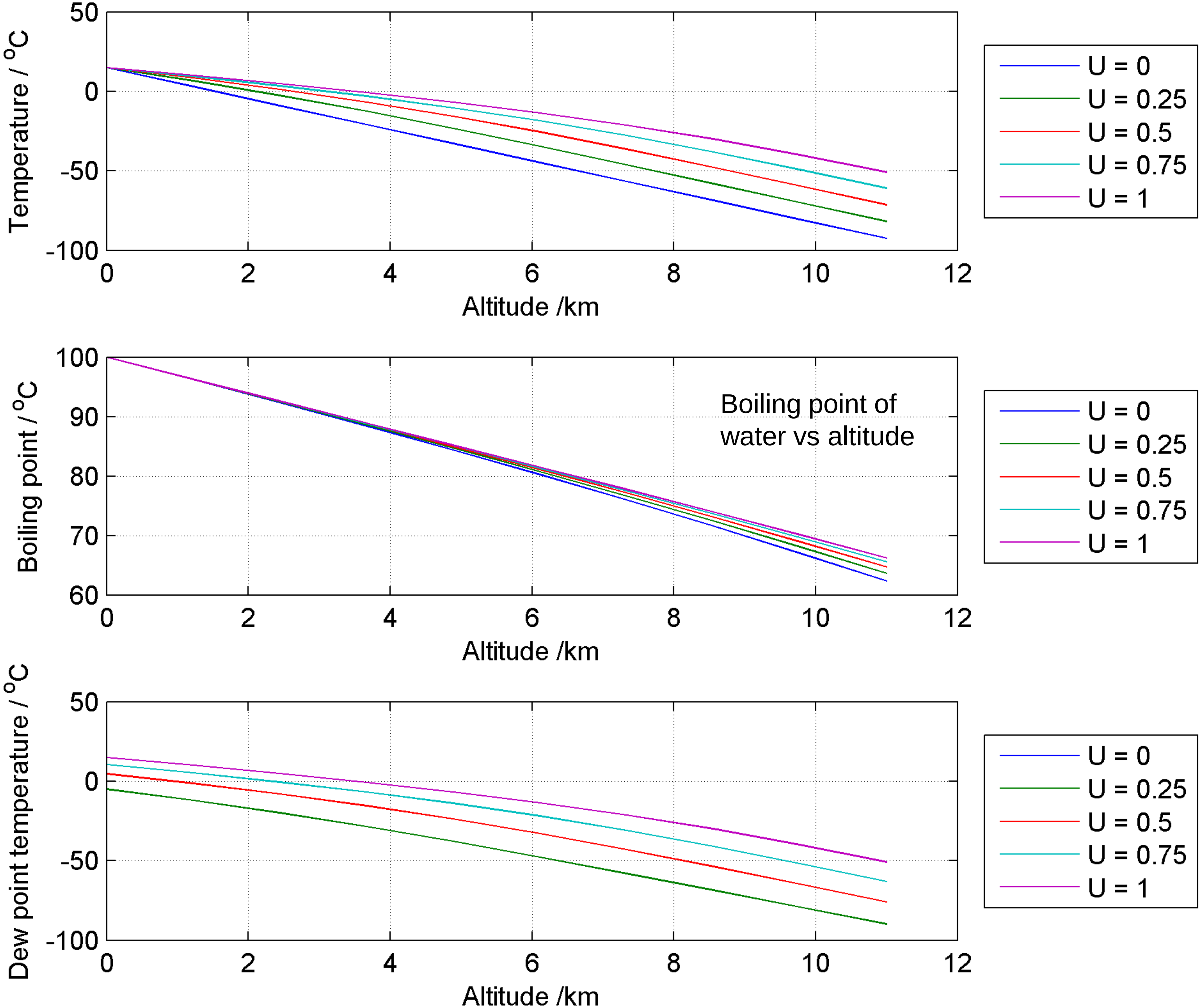


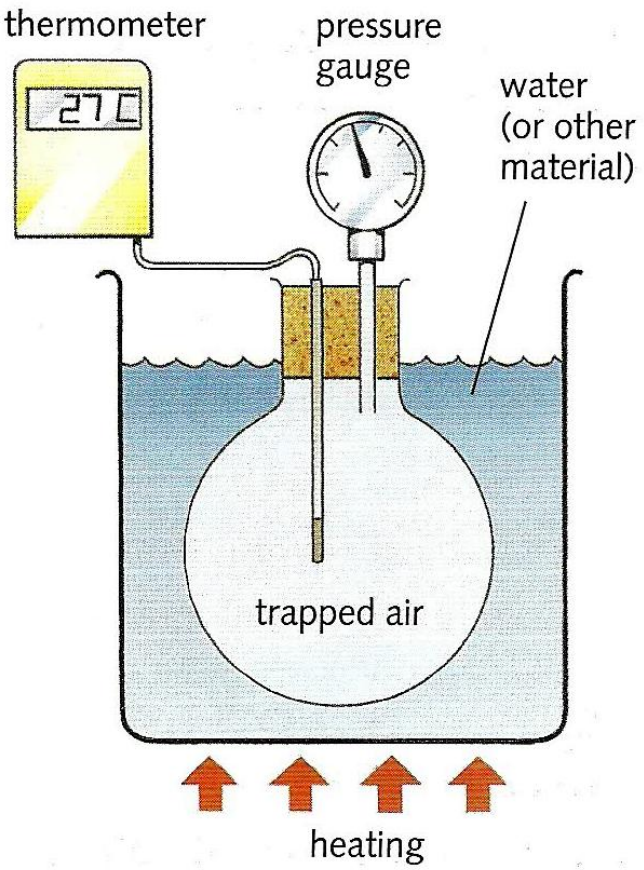


Note in the *thermosphere* the temperature (i.e. mean kinetic energy of air molecules) can rise to *several thousand degrees Celsius.* However, the air density is *extremely low*, which means it would still feel very cold indeed, as very little heat could be extracted from a given volume of air.

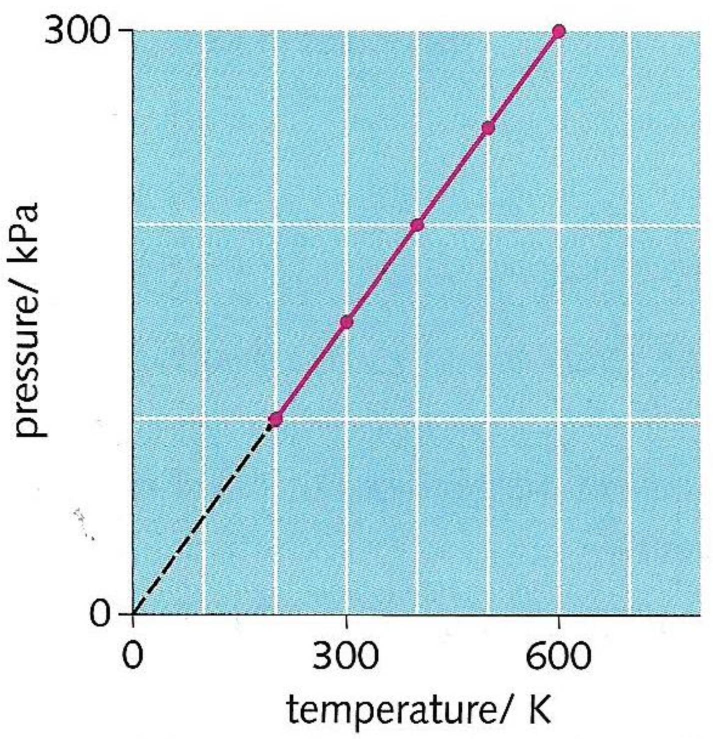


U = 1 means 'wet air'
U = 0 means dry air


Temperature / °C
Altitude /km
U = 0
U = 0.25
U = 0.5
U = 0.75
U = 1
Boiling point / °C
Boiling point of water vs altitude
Dew point temperature / °C



pressure kPa	temperature °C	temperature K
100	−73	200
150	27	300
200	127	400
250	227	500
300	327	600



At **constant volume**, an *ideal* gas obeys the equation

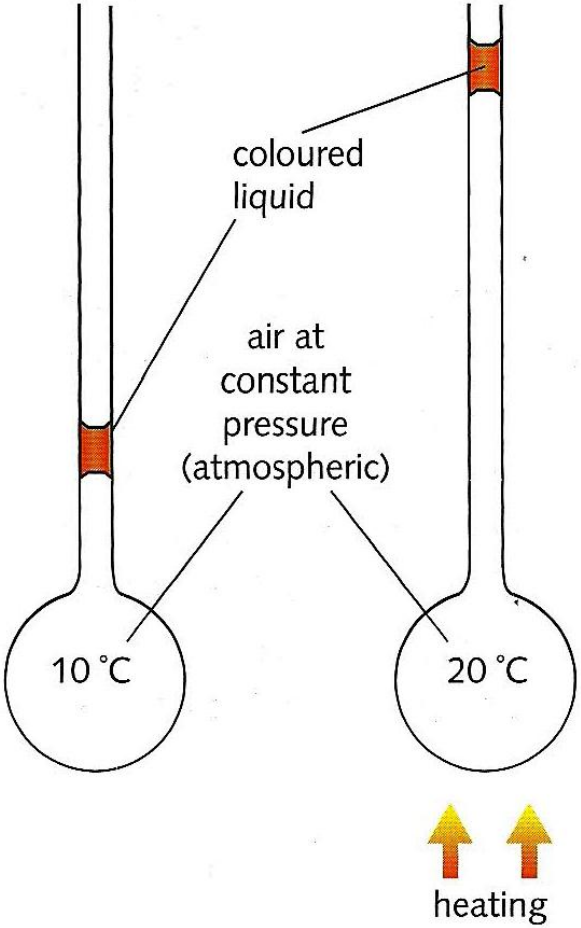
$$P \propto T$$

i.e. we don't worry about the gas inter-molecule forces. They collide and transfer energy elastically.

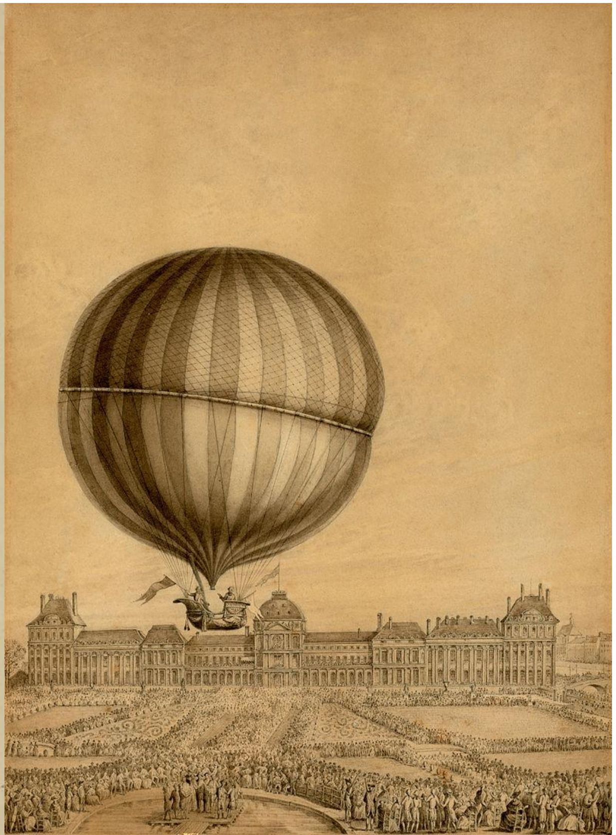
Charles' Law states

At **constant pressure**, an *ideal* gas obeys the equation

$$V \propto T$$



Jacques Charles (1746-1823)

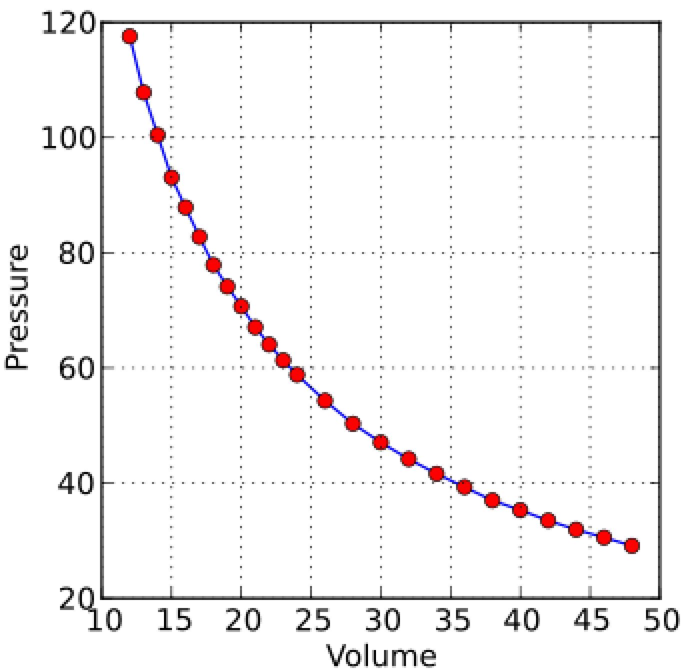


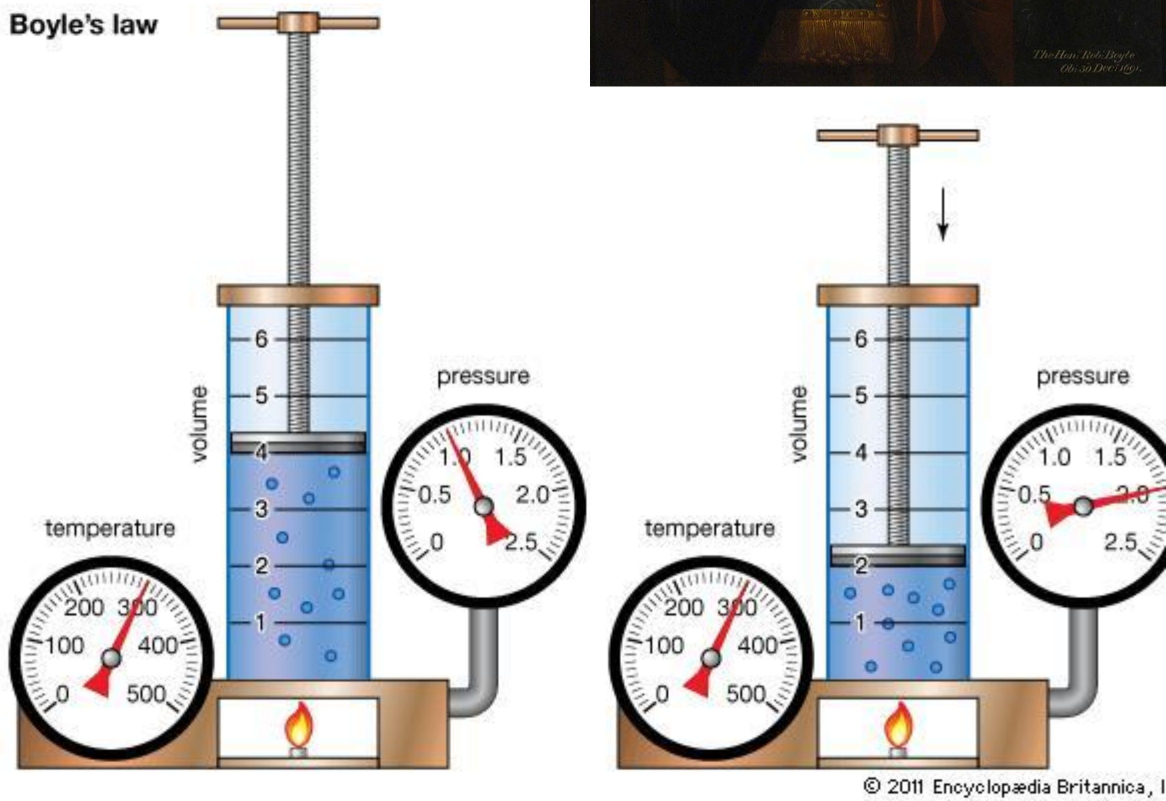
Robert Boyle (1627–91)

Boyle's Law states

At **constant temperature**, an *ideal* gas obeys the equation

$$P \propto \frac{1}{V}$$





The Ideal Gas Equation

Temperature in Kelvin

$$PV = nRT$$

Pressure in Newtons / square metre (Pascals or Pa)

Gas volume in cubic metres

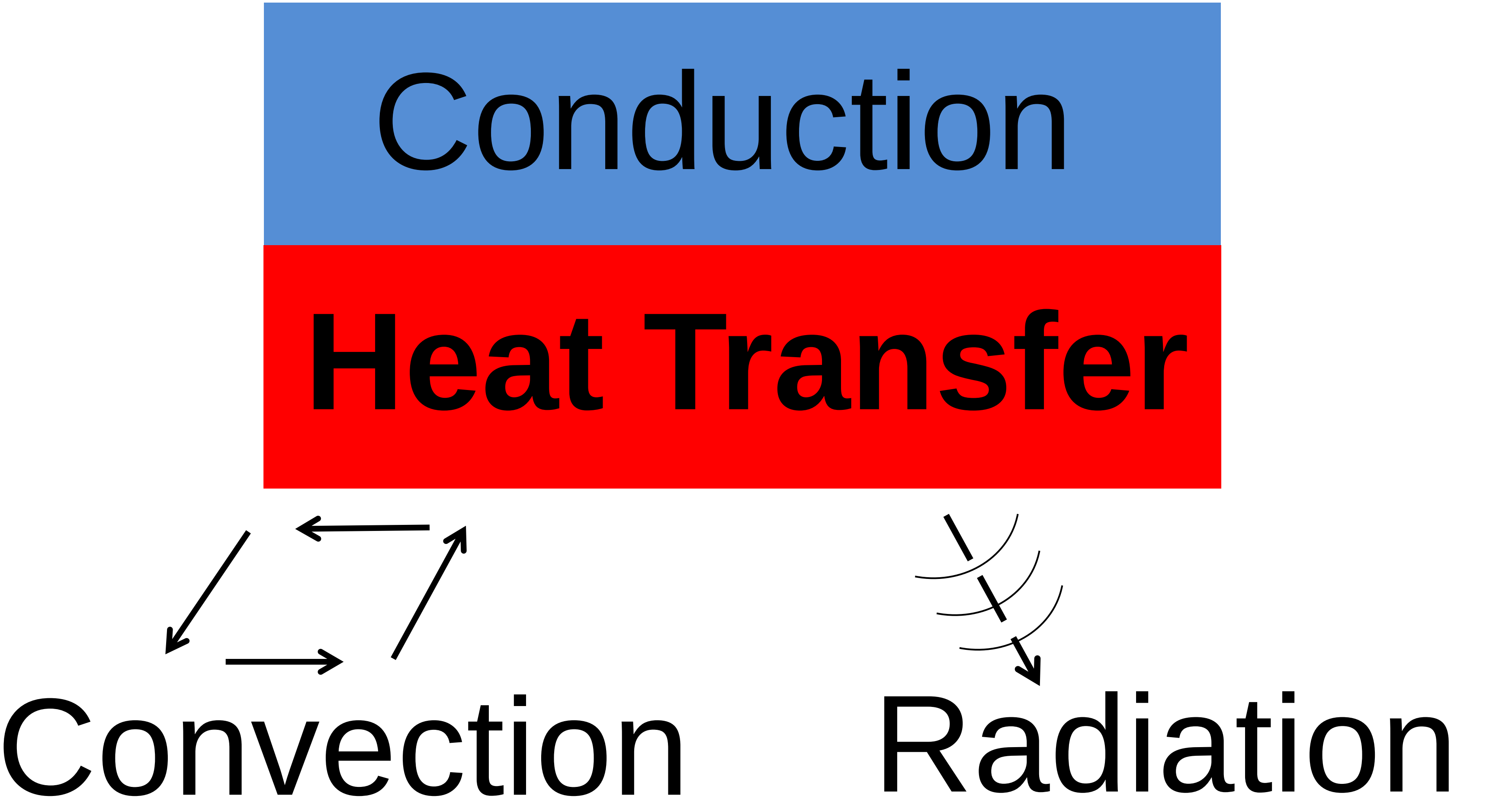
Number of moles of gas

Molar Gas constant
$R = 8.314\ Jmol^{-1}K^{-1}$

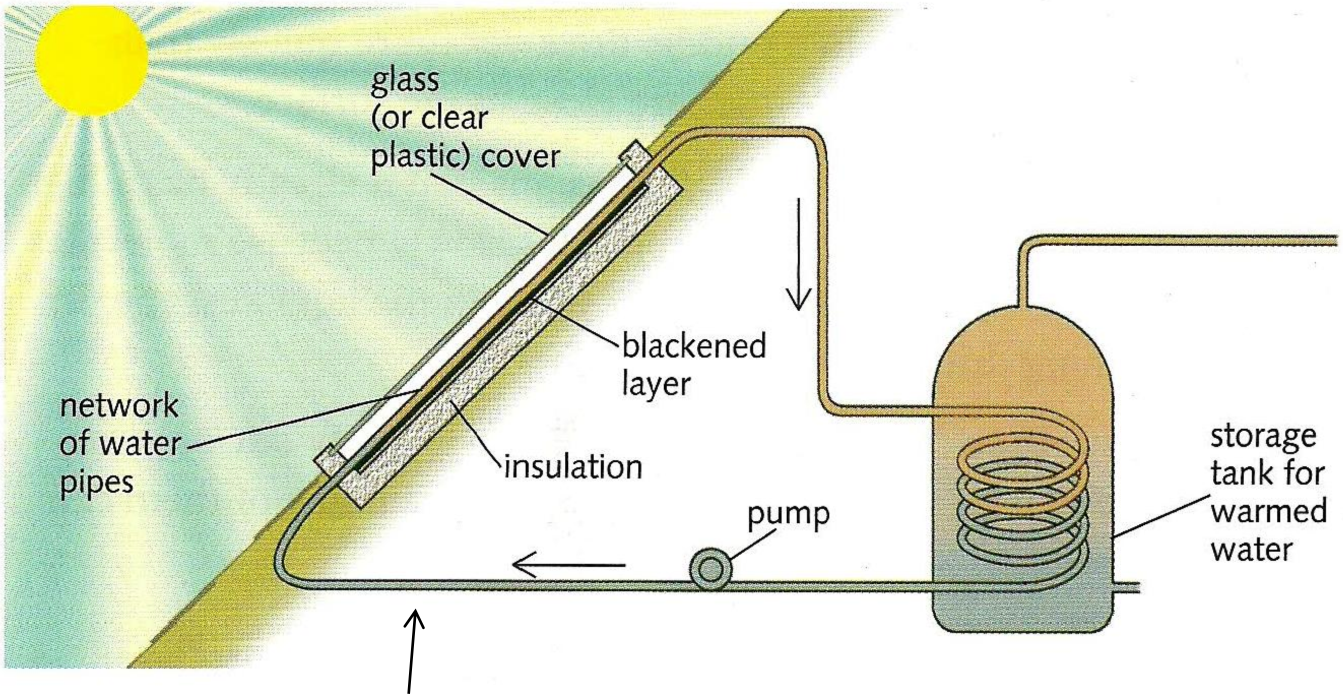
Avogadro's number
6.02×10^{23} molecules per mole

1 atmosphere = 101,325Pa
1 bar = 100,000 Pa
1mbar = 100 Pa

Note real gases are *not* ideal – when molecules get close enough there are **intermolecular forces** which will significantly effect the motion of the molecules. However, the 'ideal gas' approximation is typically a good one in most practical situations.

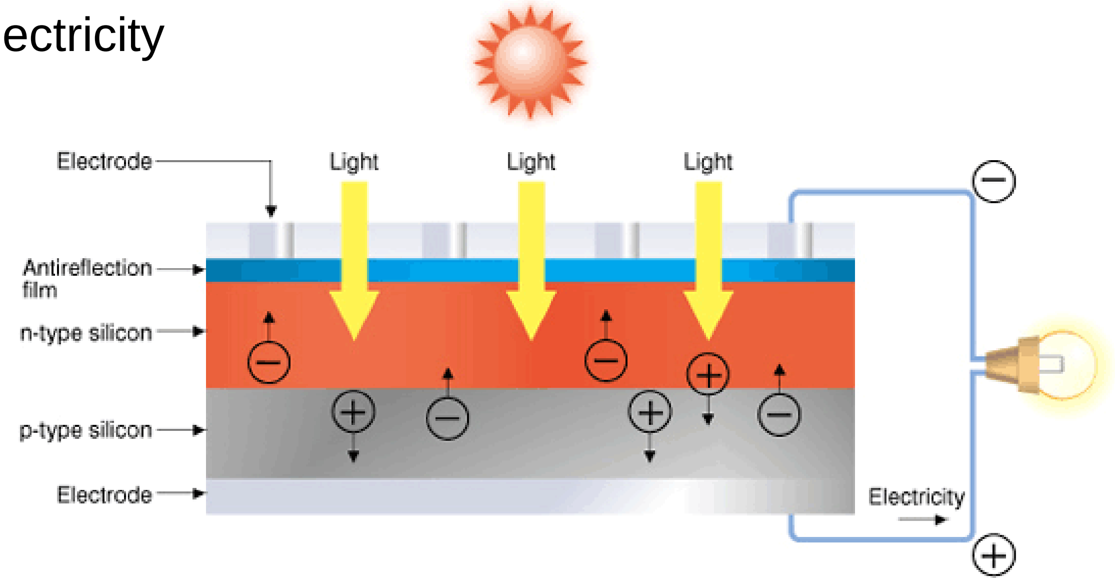

Conduction
Heat Transfer
Convection
Radiation

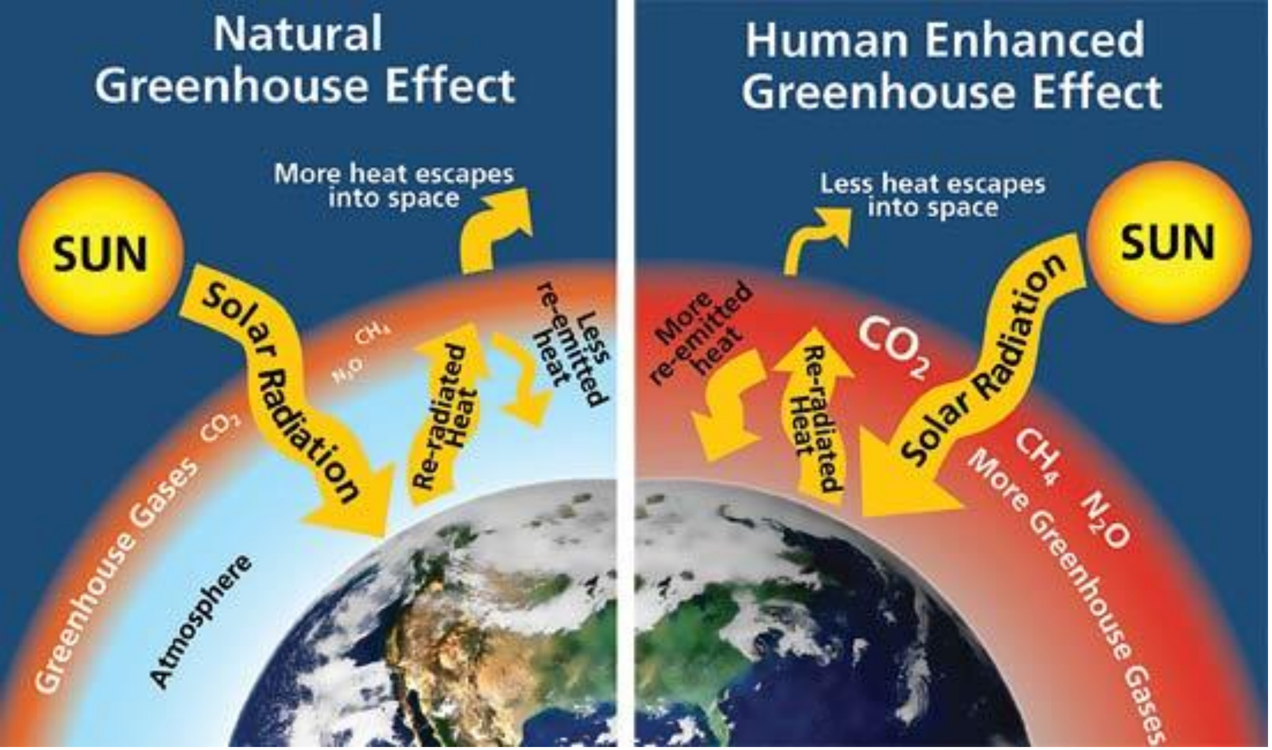
The Solar Panel

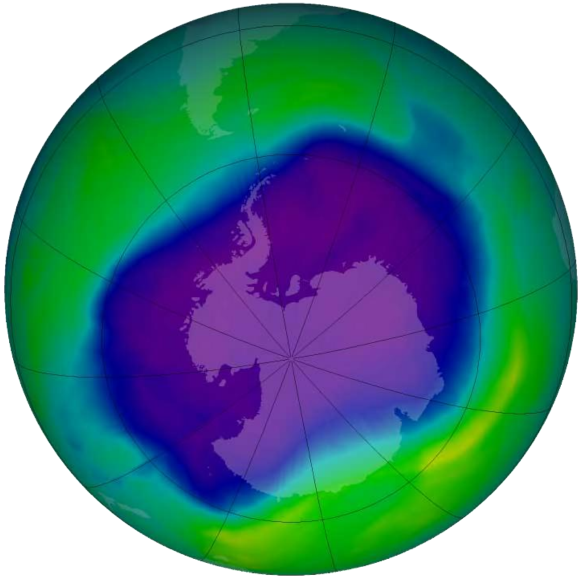


This is a *passive* solar heater.
An *active* solar panel generates electricity directly using a photovoltaic cell

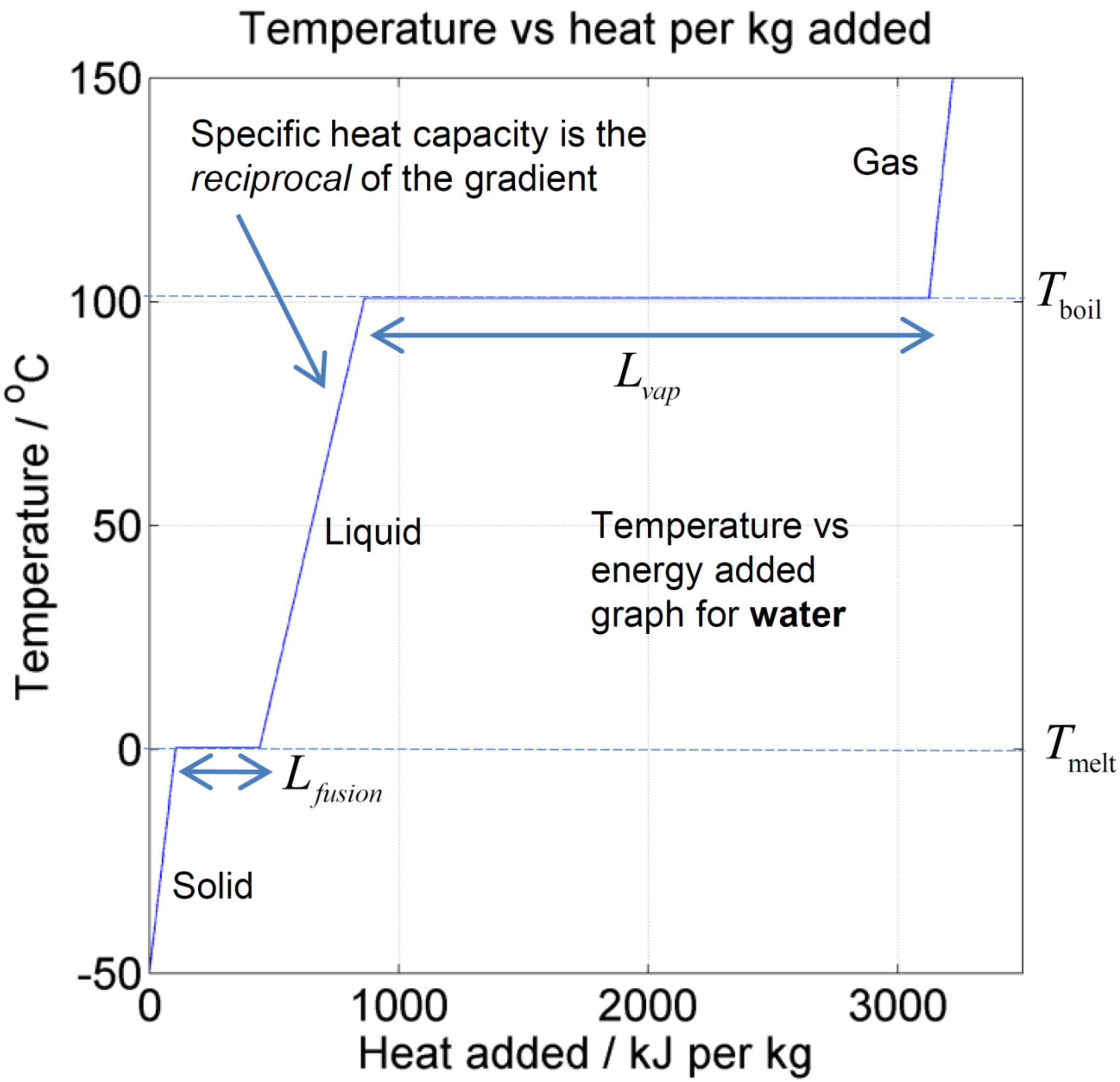
How a Photovoltaic cell generates power

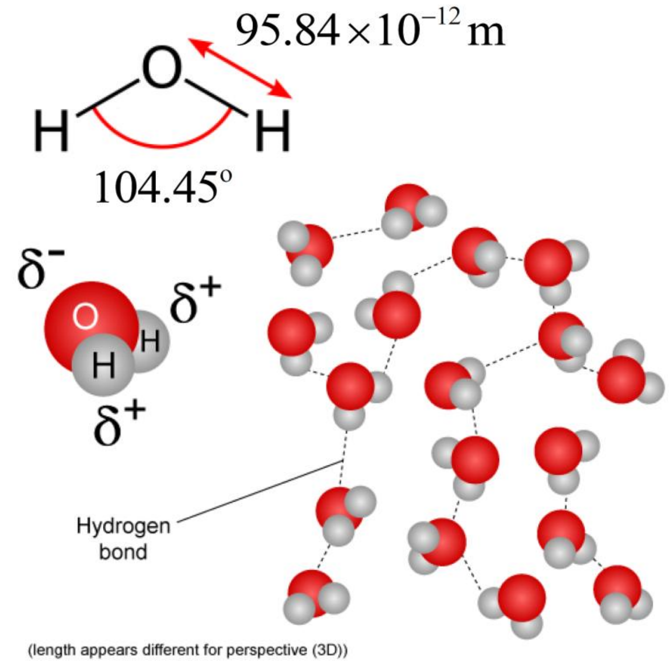






The Eden Project



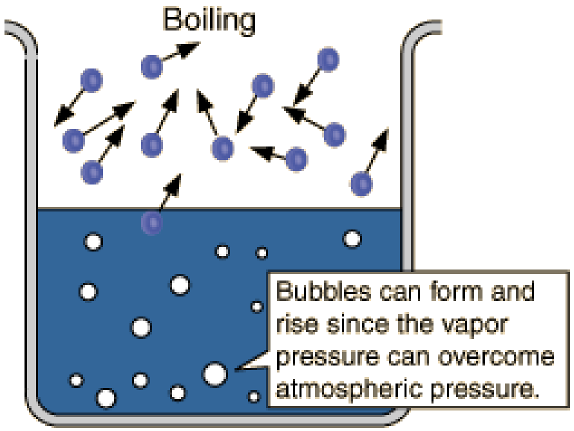


	Melting temp. / °C	Boiling temp. / °C	Latent heat of fusion / x 10^4 Jkg^{-1}	Latent heat of vaporization / x 10^5 Jkg^{-1}	Specific heat capacity (solid) / $Jkg^{-1}K^{-1}$	Specific heat capacity (liquid) / $Jkg^{-1}K^{-1}$	Specific heat capacity (gas) / $Jkg^{-1}K^{-1}$
Water	0	100	33.5	22.6	2,090	4,186	1,930

Boiling

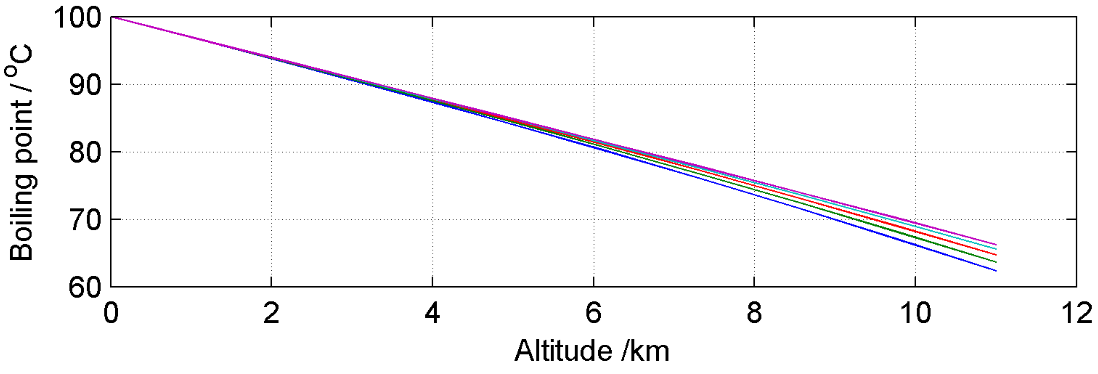
Liquid water will contain bubbles of **vapour**. At 20^{o}C at sea level these are tiny, due to the pressure of the atmosphere and the relatively modest temperature. The bubbles will expand if:

(i) the atmospheric pressure drops or
(ii) the temperature rises



Rapid mass bubble expansion, followed by bursting and vapour release is in practical terms what **boiling** is i.e. the **conversion of liquid to gas**.

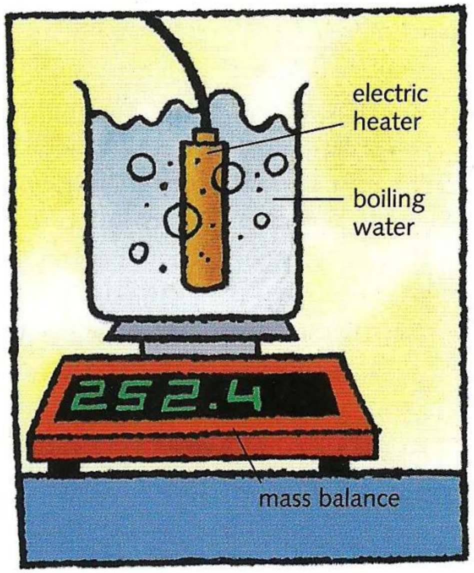
At 100^{o}C at sea level, water will boil. Due to the lowering of atmospheric pressure with altitude, the boiling temperature reduces. At the summit of Mount Everest (8848m) water boils at about 70^{o}C.

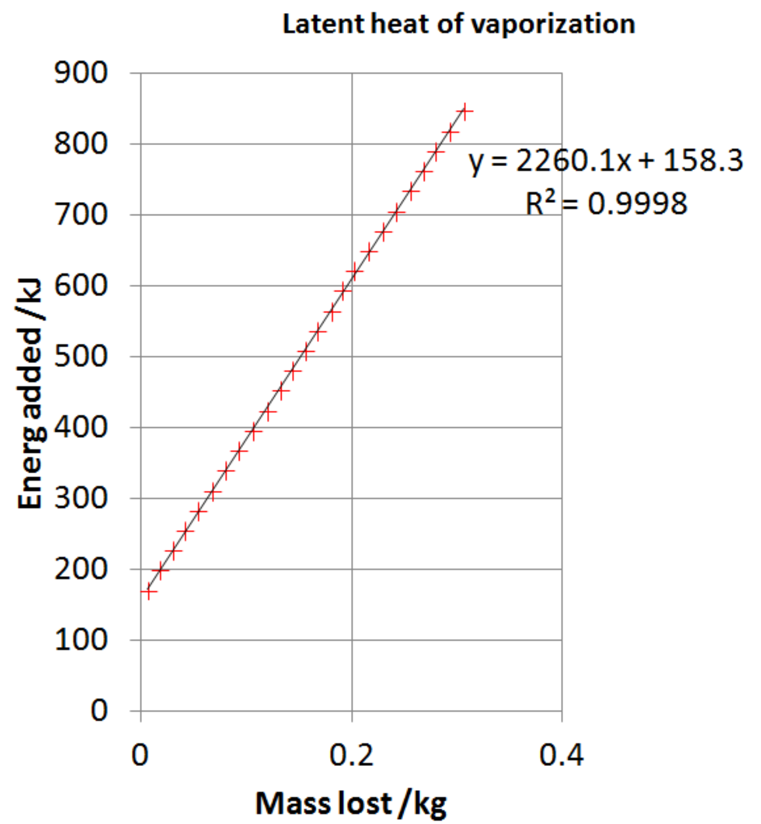


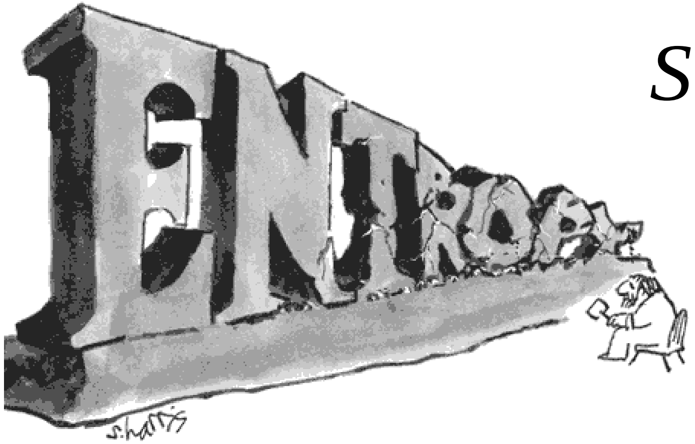
Voltage	235.00
Current	4.00

Power /kW 0.94

	t/s	**Energy added /kJ**	**mass lost /g**	**mass lost /kg**
	0	0	0	0
	30	28.2	-0.4	-0.0004
	60	56.4	0.3	0.0003
	90	84.6	0.9	0.0009
	120	112.8	0.7	0.0007
	150	141	1.1	0.0011
BOIL	180	169.2	5.9	0.0059
	210	197.4	16.8	0.0168
	240	225.6	29	0.029
	270	253.8	41.4	0.0414
	300	282	53.7	0.0537
	330	310.2	67.5	0.0675
	360	338.4	80	0.08
	390	366.6	92.2	0.0922
	420	394.8	105.2	0.1052
	450	423	118.9	0.1189
	480	451.2	132.1	0.1321
	510	479.4	142.9	0.1429
	540	507.6	155.2	0.1552
	570	535.8	166.5	0.1665
	600	564	179.9	0.1799
	630	592.2	190	0.19
	660	620.4	201.8	0.2018
	690	648.6	215.4	0.2154
	720	676.8	228.5	0.2285
	750	705	241.3	0.2413



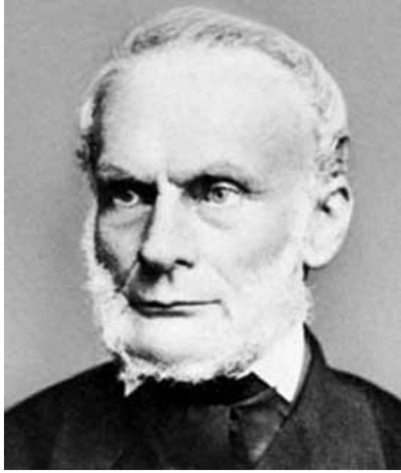




$$S = k_B \ln W$$

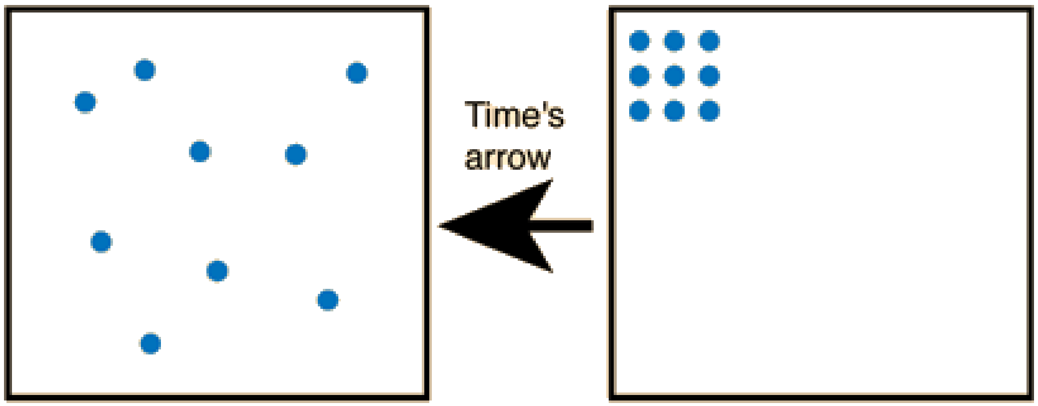
“Number of ways of arranging energy”

Ludwig Boltzmann 1844-1906

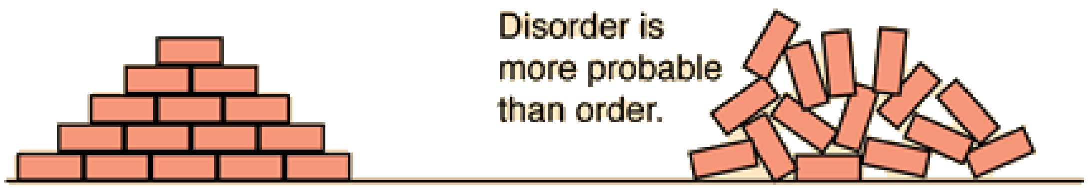


Rudolf Clausius 1822–1888

If the particles represent gas molecules at normal temperatures inside a closed container, which of the illustrated configurations came first?



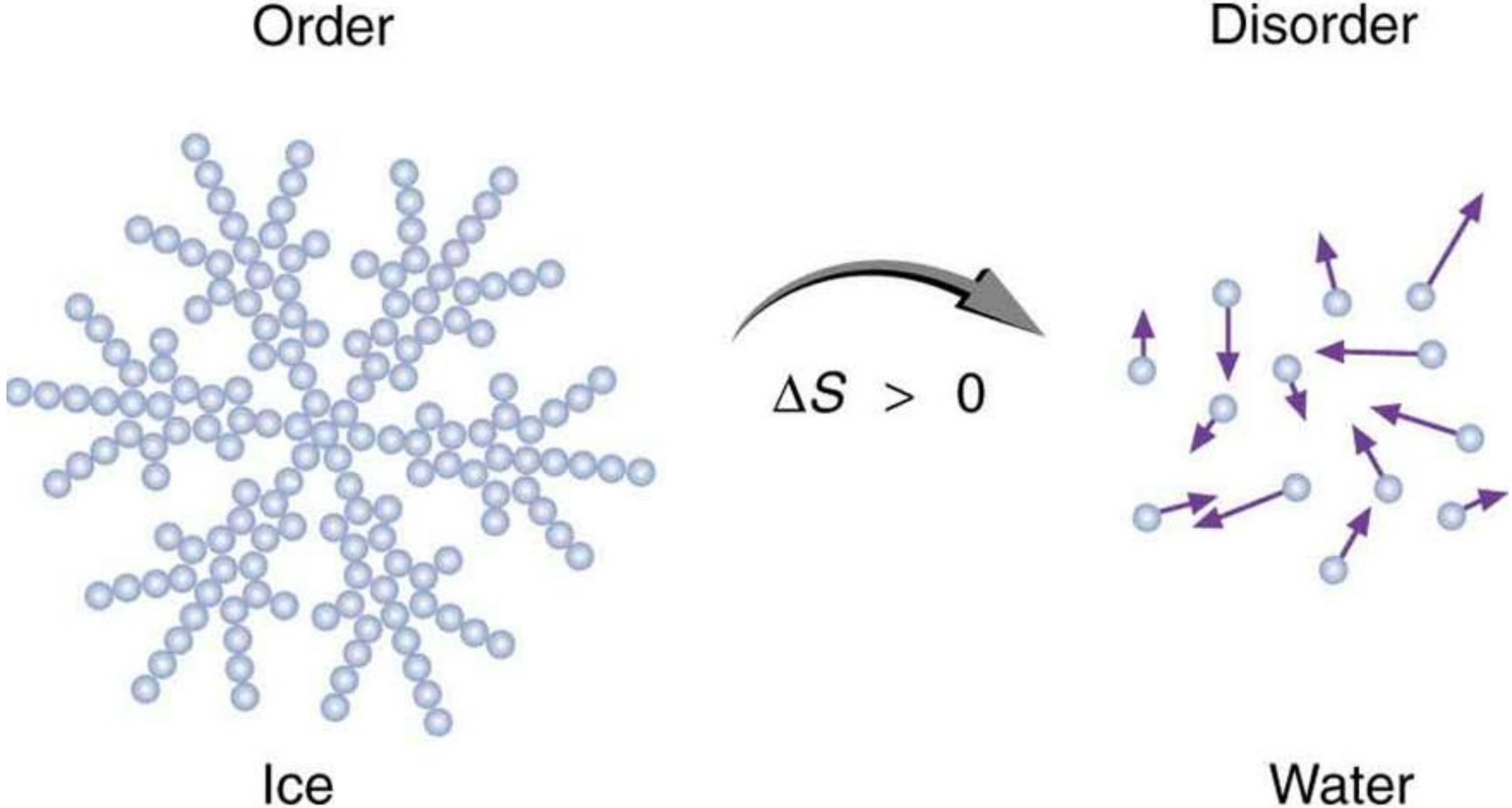
If you tossed bricks off a truck, which kind of pile of bricks would you more likely produce?

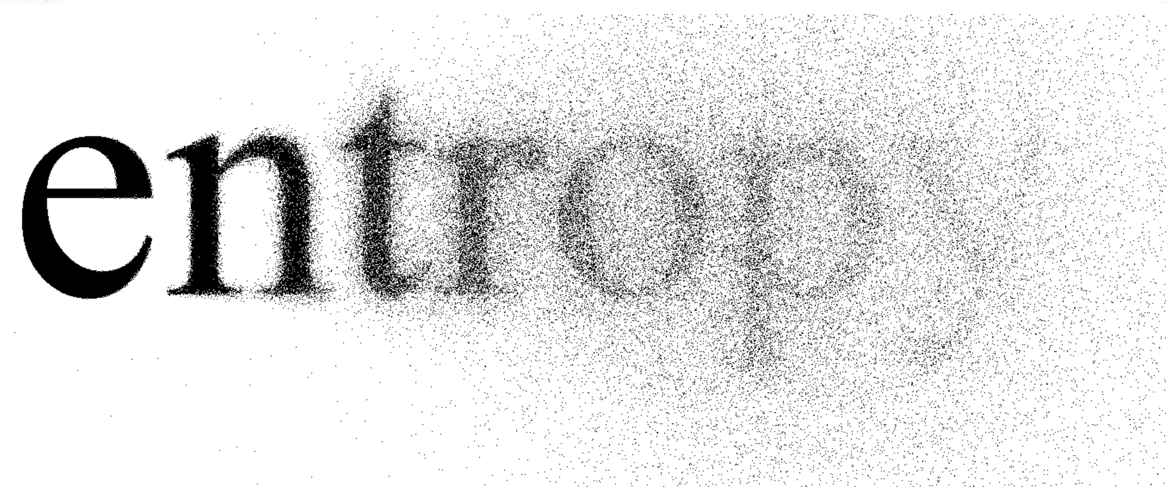


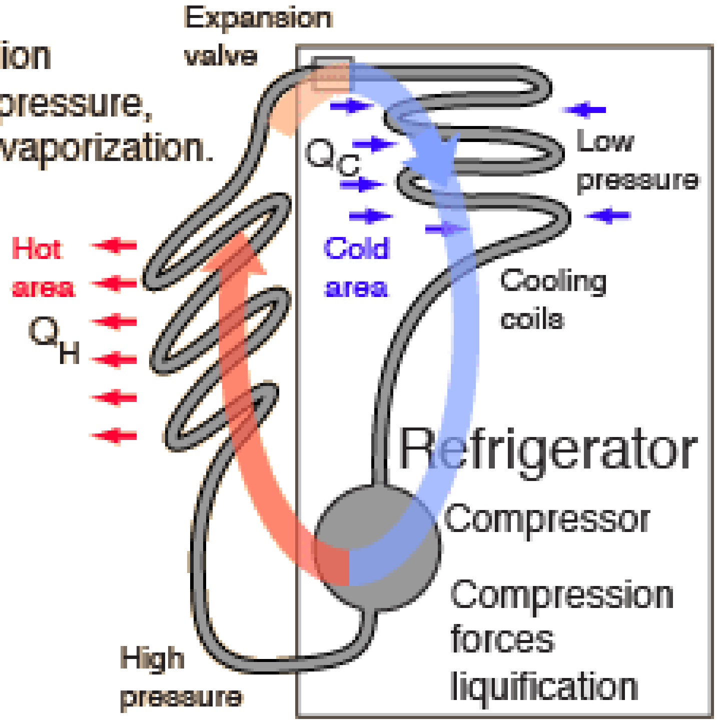
Second Law of Thermodynamics

For all processes, the overall entropy of the universe must increase

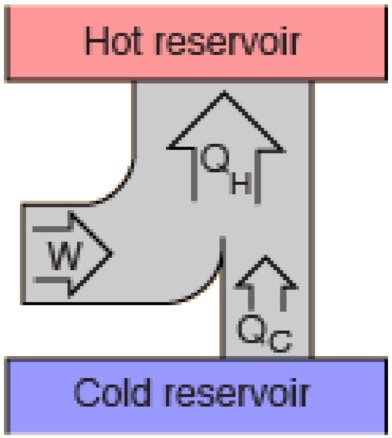
Which is why **tidying up** requires **work!**


Order
Disorder
$\Delta S > 0$
Ice
Water


entrop



All real refrigerators require work to get heat to flow from a cold area to a warmer area.



In order to cool a fridge we need to ‘pump’ heat from a cold region (inside the fridge) to a hotter region (surrounding air).

To satisfy the *Second Law of Thermodynamics* we must **do work** to make this happen

A flow of heat from hot to cold regions will happen *without* a work input!

Topics to reflect on:

Energy. Formula for **kinetic energy**. **Conservation of energy.**

Kinetic theory: The **molecular** model of **heat**. Difference between **heat** (total energy flow) and **temperature** (average kinetic energy per molecule).
States of matter: **Solid**, **Liquid** and **Gas**

Heat transfer: **Conduction**, **convection** and **radiation**

The **atmosphere** and the **Greenhouse effect**

The **Ideal gas**: **Pressure**, **Volume**, **Temperature**

Specific heat and **boiling**

Entropy – a measure of disorder

Depending on your course, we may not cover all of these. Review the topics you did meet. If you have time to spare, read on!