PHAS1000 – THERMAL PHYSICS

Lecture 1

Temperature

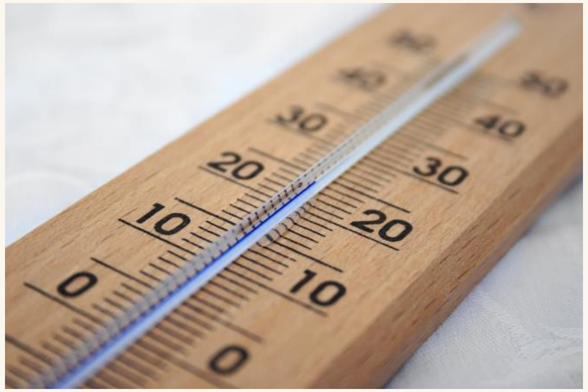


Image: pixabay.com

Thermal Physics

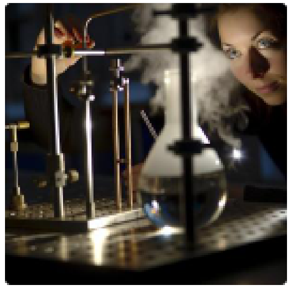
Prof Alison Voice

a.m.voice@leeds.ac.uk

Bragg 1.35 D

Week	TUESDAYS @ 12pm in CAPE LTA (2.23)	THURSDAYS @ 11am in RSLT 20	THURSDAYS at 1pm OR 2pm in RSLT 8
3	Temperature, Absolute Zero	Heat, internal energy, zeroth law	
4	Thermal expansion	Conduction, convection, radiation	WORKSHOP 1
5	Kinetic Theory + Ideal gas	Partial pressure	
6	Pressure with depth & altitude	Maxwell Boltzmann distribution	WORKSHOP 2
7	Molar heat capacity, Equipartition	Quantum explanation of Equipartition, Dulong-Petit law	
8	1st Law, Mayer's equation	Isochoric and isobaric processes.	WORKSHOP 3
9	Isothermal processes, Joule-Thompson effect	Adiabatic processes	
10	Thermal Physics in action	Sustainability Development Goals	WORKSHOP 4
11	Revision	Revision	

Minerva



Topic: Thermal Physics (Professor Voice)

Visible to students

Timeline

Visible to students

Lecture 1: Temperature

Visible to students

Here are OUTLINE slides for Tuesday's lecture (pptx and pdf)

Lecture 1 - TEMPERATURE - OUTLINE.pptx

Lecture 1 - TEMPERATURE - OUTLINE.pdf

After the lecture I will post FINAL slides with all the writing etc from the session, along with the recording.

Note Taking and Good Study Habits

- Have you developed a preferred method of taking notes?
  Electronic or hand written. On the slides, or on paper.
  It keeps you focussed (awake) and personalises your notes to aid memory and understanding.

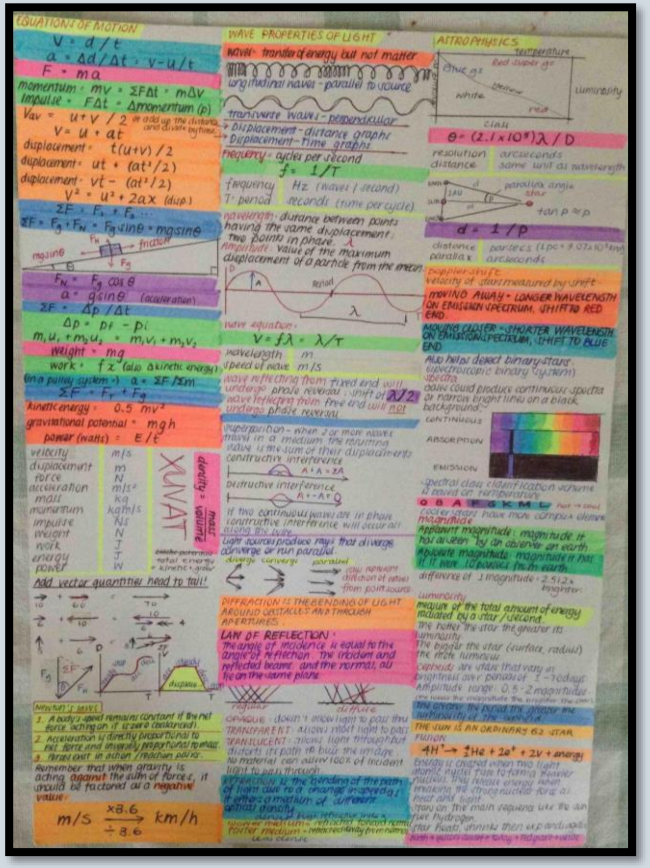
- Out of class, good to read through and add to your notes before the next session. Use text book or internet or re-watch some of the recording.

- Keep a running summary of important equations, laws, graphs, etc. for each Topic
  Add to it each week. Look back over it regularly and test yourself on it.
  Use it when doing questions. Can help form your crib sheet.

Image: www.pexels.com

Crib Sheet

- You can take a one page (both sides) A4 crib sheet into the exam.
- This can contain anything you like (equations, graphs, units, etc)
- This is NOT a substitute for good revision.



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What to do if you get behind with study

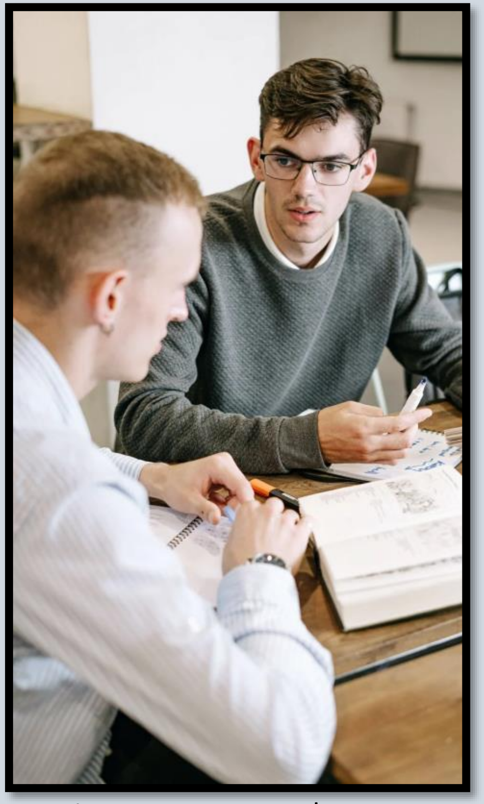
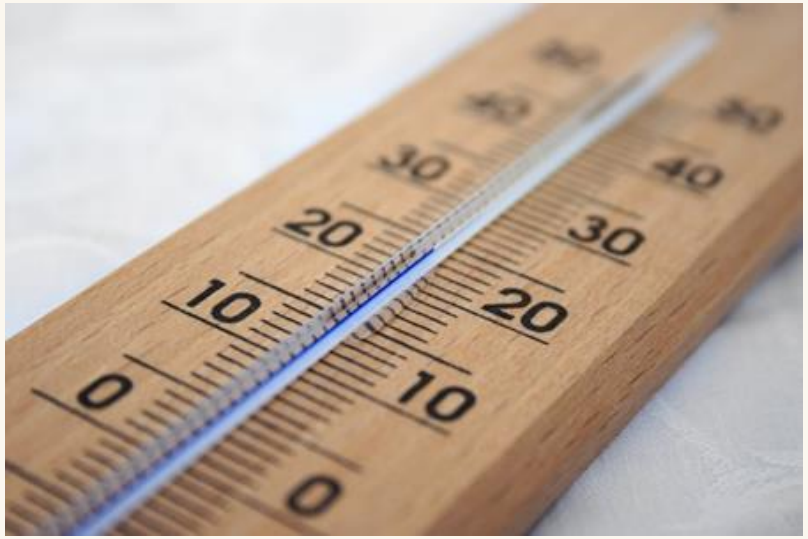


Image: www.pexels.com

- If you get behind (for whatever reason) get back on track quickly. You can't recover time you have lost, so find ways to study efficiently.

- Maybe watch recordings at double speed, and take only brief notes.
- Maybe ask a friend to explain the sessions you have missed (that will consolidate your friend's understanding as well).
- Maybe just 'park' the missed work, and concentrate on the current material. Although be aware of when VITALS are tested.
- But don't spend the whole term a week or so behind everyone else.

Overview – This lecture

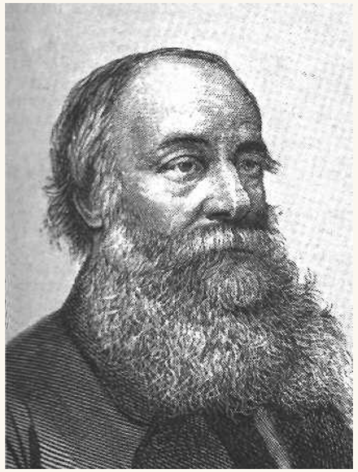


We will look at:

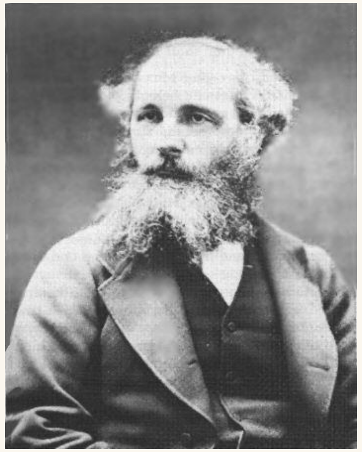
- Intro to Thermal Physics
- What is Temperature
- Absolute zero

What is Thermodynamics?

Robert Boyle
1627-1691

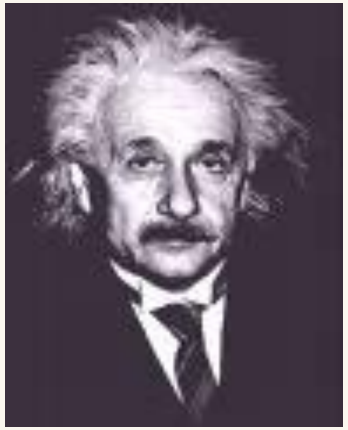


James Joule
1818-1889



James Clerk Maxwell
1831-1879

Ludwig Boltzmann
1844-1906



Albert Einstein
1879-1955

17TH CENTURY

Pressure Volume

Temperature

19TH CENTURY

Industrial Revolution

Engines, efficiency

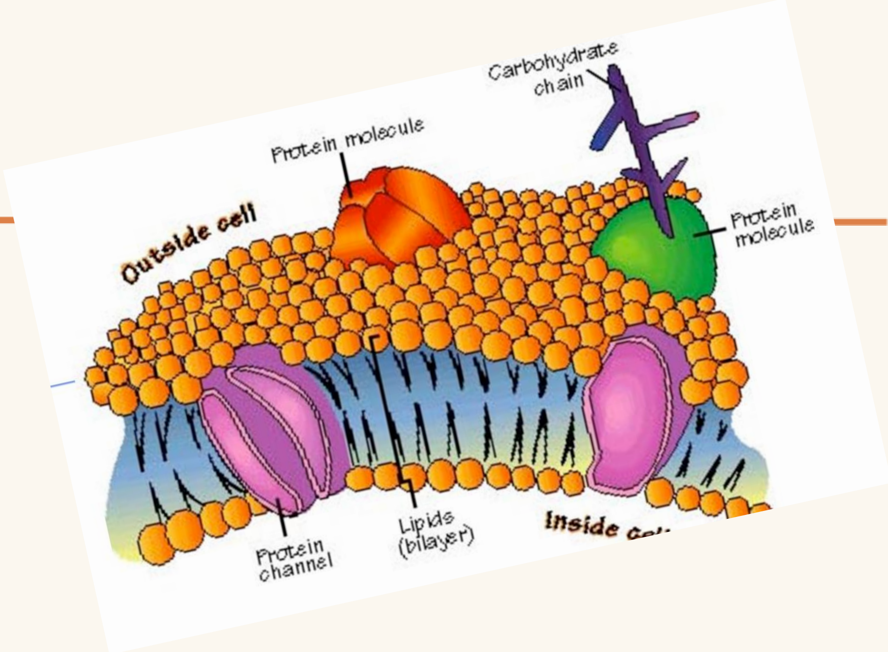
Work, heat

20TH CENTURY

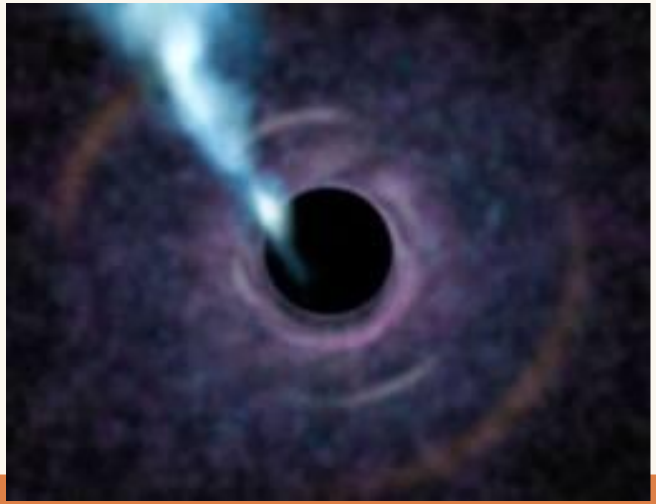
Statistical Mechanics

Quantum explanations

21TH CENTURY



Atmospheric physics, Climate
Black holes, Astrophysics
Biological systems, development of complexity
Quantum computing
Economics



Temperature

Tell me something about temperature.

Answer any (or all) of the questions below

- ❑ What is temperature?
- ❑ What is the SI unit of temperature?
- ❑ Is there a maximum or minimum limit to temperature?
- ❑ How do we measure temperature?

Join at:
vevox.app

ID:
199-145-020

Temperature

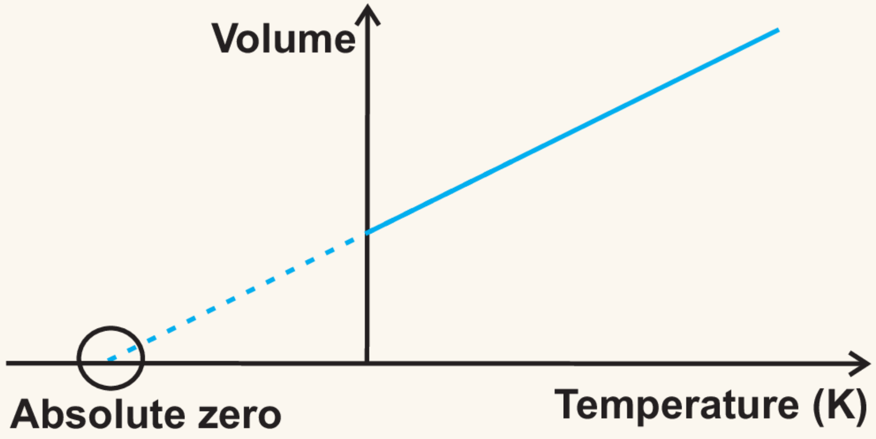
SI unit of temperature is Kelvin (K)

T(K) = T(°C) + 273.15

For **change** of temperature: rise of 1 K = rise of 1 °C

Lowest possible temperature is 0 K, Absolute Zero
No theoretical upper limit of temperature.

Ideal gas at constant pressure

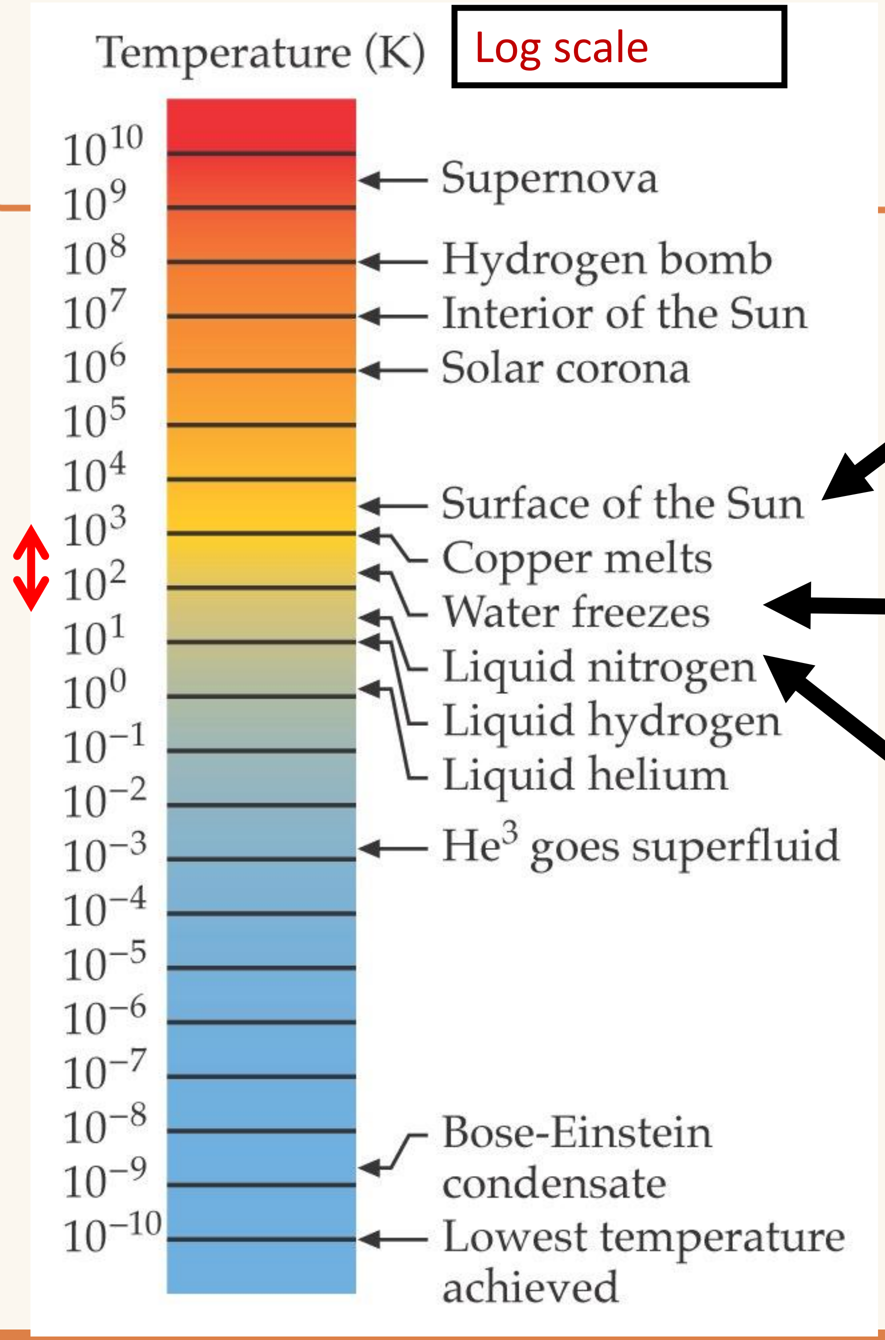


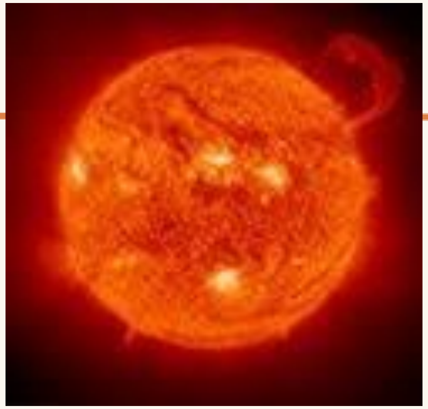
Temperature is a measure of average translational kinetic energy of the atoms or molecules

T $\propto$ average KE $$\frac{3}{2}kT = (KE)_{av} = \frac{1}{2}m(v^2)_{av}$$ k = Boltzmann's constant 1.38 x 10^{-23} J/K

At absolute zero all atoms and molecules are at rest.
They have given up all their thermal energy.

Temperatures





Cooling

How do we cool something?

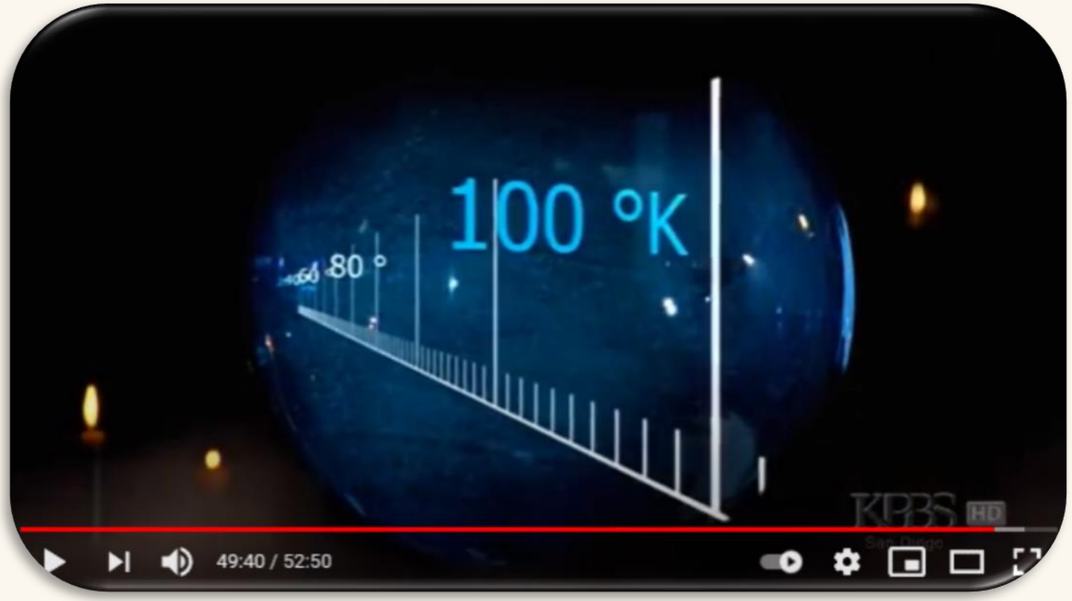
Let it evaporate,
loses molecules with most KE.

Leave in cool room (or fridge). Heat flows from hot coffee to cooler room (or fridge).

Add some cold milk. Heat transfers from coffee to milk. (milk warms up).

How do we cool something colder than its surroundings?

Cooling to Absolute Zero



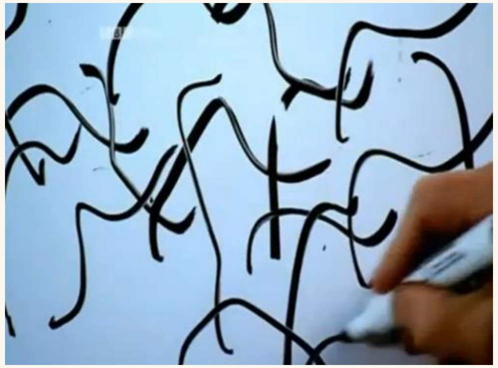
https://mymedia.leeds.ac.uk/Mediasite/Play/83b622a070ca4dbc9b84708ab05a562d1d
Click on this link, or the picture to view.

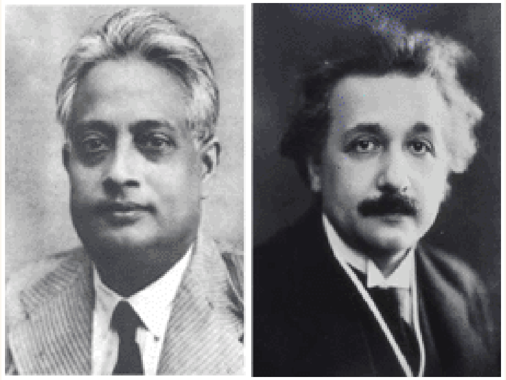
The clips in this video are taken from 'The Race to Absolute Zero' by PBS NOVA in association with BBC (2007).

1. How does matter behave as we approach absolute zero?

(watch from start to 4.37)

Bose Einstein Condensate





Satyendra Bose 1894-1974

Albert Einstein 1879-1955

Bose Einstein condensate:

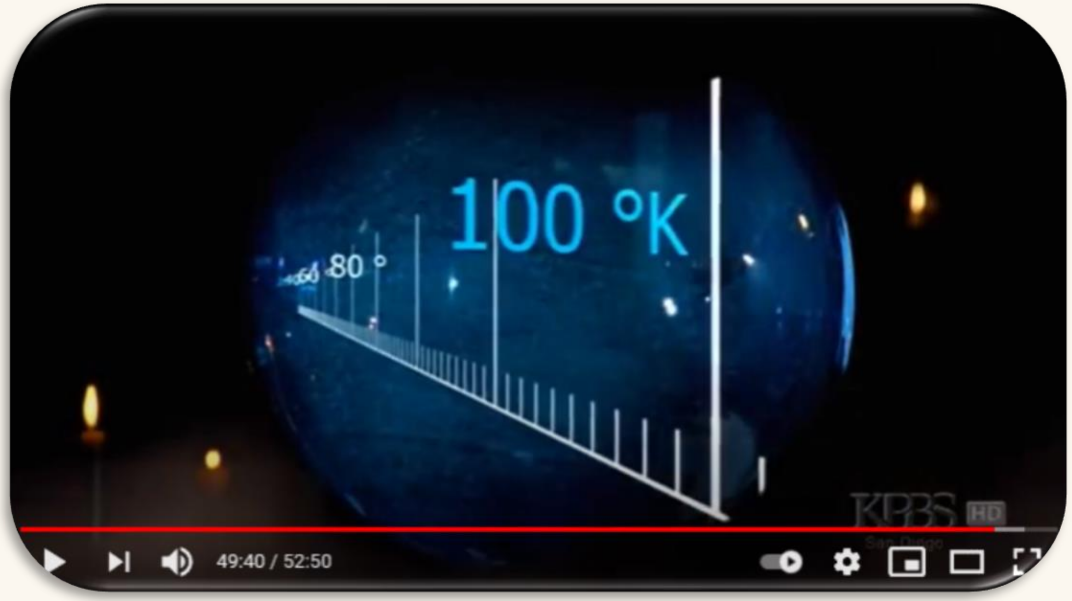
This is when the de Broglie wavelength of the atoms becomes bigger than the atomic spacing.

$$\lambda = \frac{h}{p} \qquad \lambda = \frac{h}{mv}$$

As temperature reduces, speed gets smaller, wavelength increases.

First BEC observed in 1995, about 70 years after first predicted

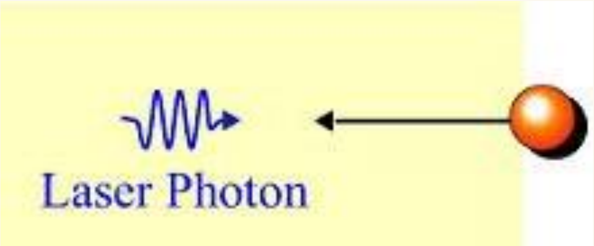
Cooling to Absolute Zero



2. How do we cool matter towards absolute zero?

(watch from 4.38 to 7.23)

Methods of Cooling (1)



Laser cooling:

- Laser photon of momentum $p=h/\lambda$ collides head on with atom of momentum $p = mv$.
- This reduces velocity of atom, so average KE and hence temperature reduced.

How do we ensure the collision does not increase the atom's KE?

- The frequency of the laser is tuned to be **below** that needed for absorption (between electron energy levels).
- **Doppler shifts** are then needed to increase the photon frequency. This only happens for photons **approaching** the atom.
- The photons are re-emitted in **random directions**, so there is no net increase in momentum of the atoms due to photon emission.

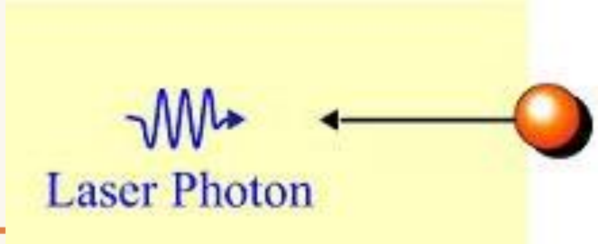
Laser Cooling example

A sample of hydrogen atoms at 0.1 K is to be cooled using laser photons.
Given the data below calculate:

(a) The average speed of the hydrogen atoms at 0.1K
(b) The number of photons needed to stop a hydrogen atom.
    (ignore any need for Doppler shifting and assume head-on collision)

Mass of hydrogen atom = 1.677×10^{-27} kg
Wavelength of relevant electronic transition = 656 nm
Planck constant = 6.6×10^{-34} Js
Boltzmann constant = 1.38×10^{-23} J/K

Laser Cooling - answer



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Boltzmann constant = 1.38×10^{-23} J/K

Photon

Wavelength = 656 nm

atom

$T = 0.1\,K$

$M = 1.677 \times 10^{-27}$ kg

(a)

$$\frac{3}{2}kT = \frac{1}{2}mv^2$$

$$3kT = mv^2$$

$$v^2 = \frac{3kT}{m}$$

$$v = \sqrt{\frac{3kT}{m}}$$

$$v = \sqrt{\frac{3 \times 1.38\times10^{-23} \times 0.1}{1.677\times10^{-27}}} = \boxed{49.69\ m/s}$$

(b) momentum of photon $p = \frac{h}{\lambda}$

momentum of atom $p = mv$

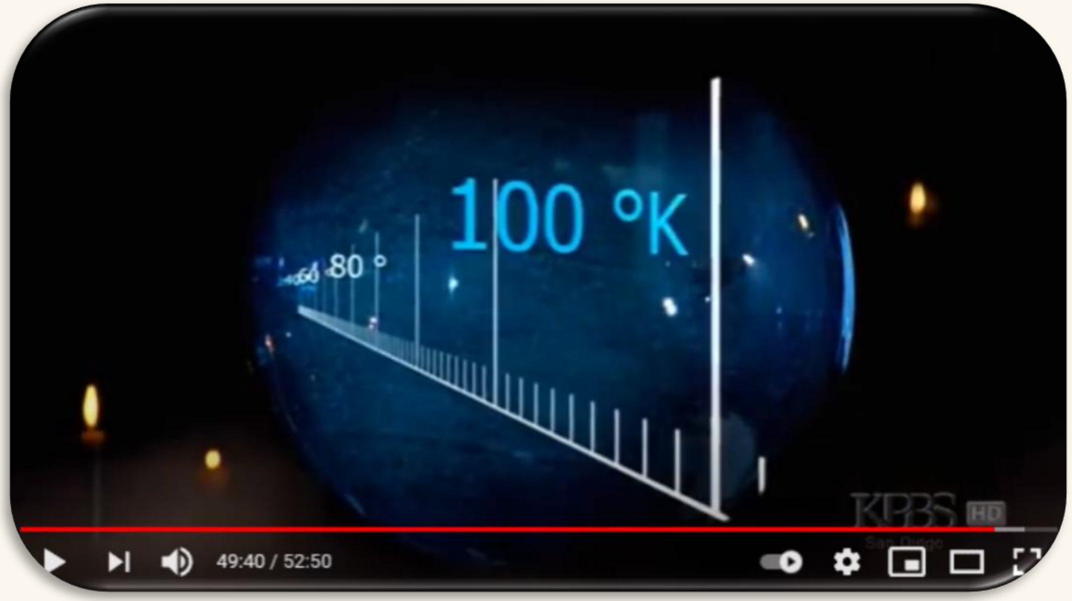
Number of photons needed $= \dfrac{\text{Mom. of atom}}{\text{Mom. of photon}}$

$$= \frac{mv}{(h/\lambda)} = \frac{mv\lambda}{h}$$

$$= \frac{1.677\times10^{-27} \times 49.69 \times 656\times10^{-9}}{6.6\times10^{-34}}$$

$$\boxed{= 82}$$

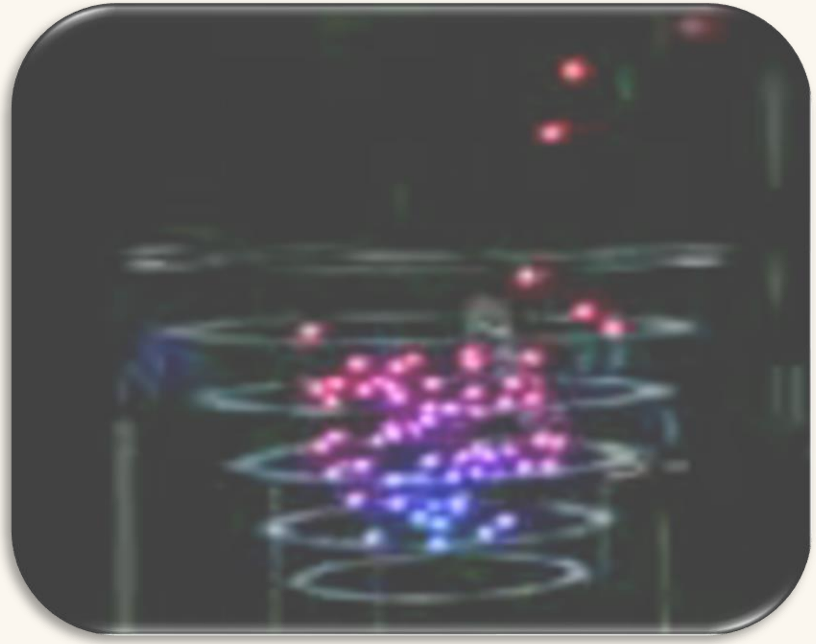
Cooling to Absolute Zero



3. Can we ever reach absolute zero?

(watch from 7.24 to 13.12)

Methods of Cooling (2)



Evaporative cooling:

Atoms held in magnetic trap. Fastest ones allowed to escape, reducing average kinetic energy hence reducing temperature.

Absolute Zero

The lowest temperature ever recorded (in 1999) in a lab is 100 pK (10^{-10} K) = 0.1 nK.

It is not possible to actually reach absolute zero, as that would take an infinite time.

Heisenberg Uncertainty Principle does not allow NO motion (we cannot specify both position and momentum precisely). Zero-point energy always remains

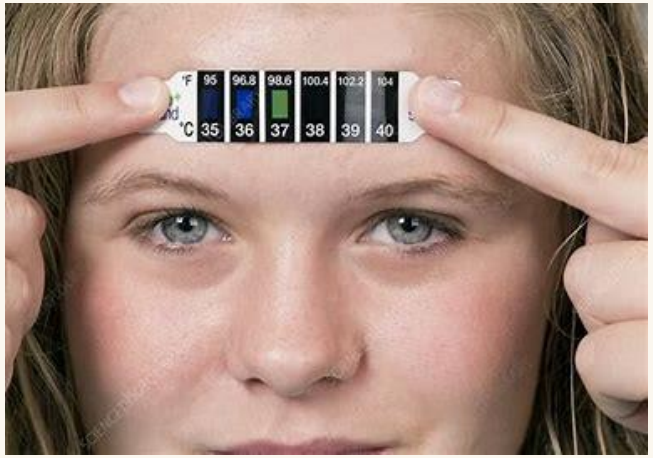
This was superceded in 2021, when a German group reached 38 pK

Thermometers

A thermometer relies on a property that changes with temperature

Liquid expansion

Thermocouple



Liquid crystal

Infrared

How can we measure temperature of the very hot or very cold?

Very high temps: peak wavelength of thermal radiation $\propto 1/T$

Very cold temps: laser light absorbed by atoms casts shadow, size $\propto T^2$

Summary

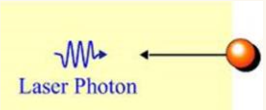
Temperature is a measure of the average translational kinetic energy per molecule

$$\frac{3}{2}kT = (KE)_{av} = \frac{1}{2}m(v^2)_{av}$$

Cooling towards Absolute Zero:

Bose Einstein condensate

Laser cooling



$$\lambda = \frac{h}{p}$$

Evaporative cooling