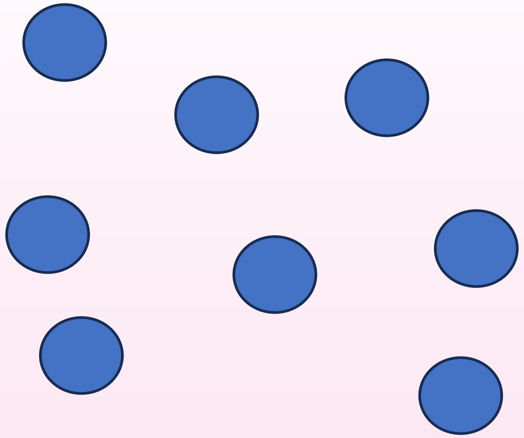
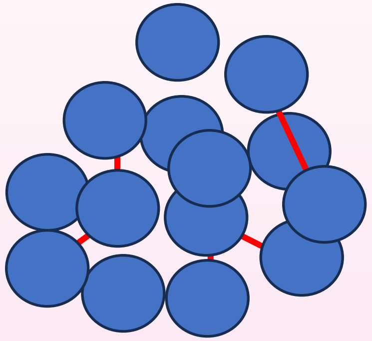
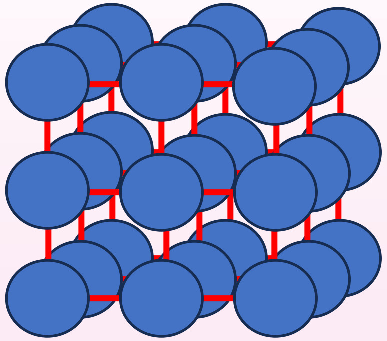
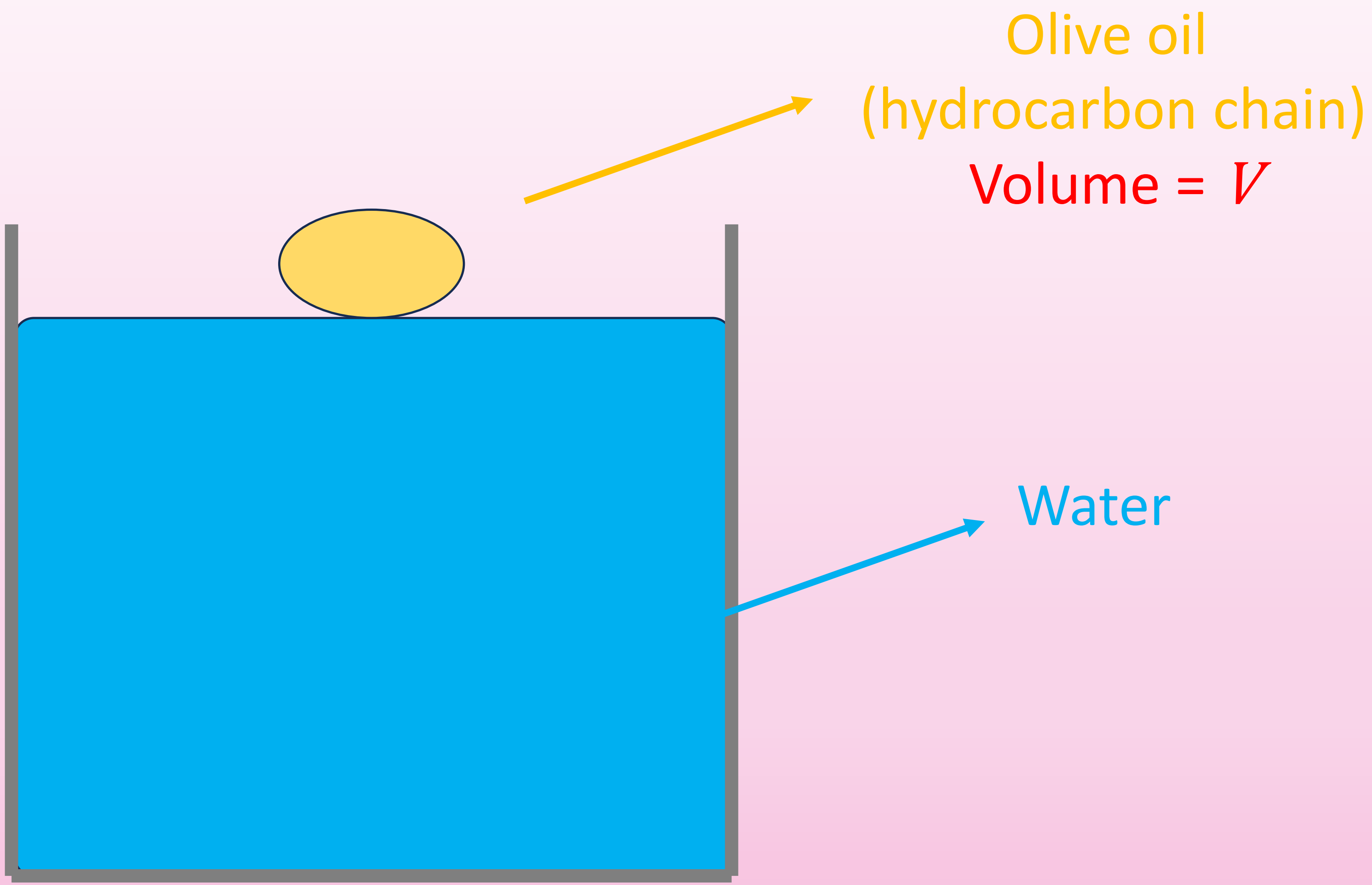
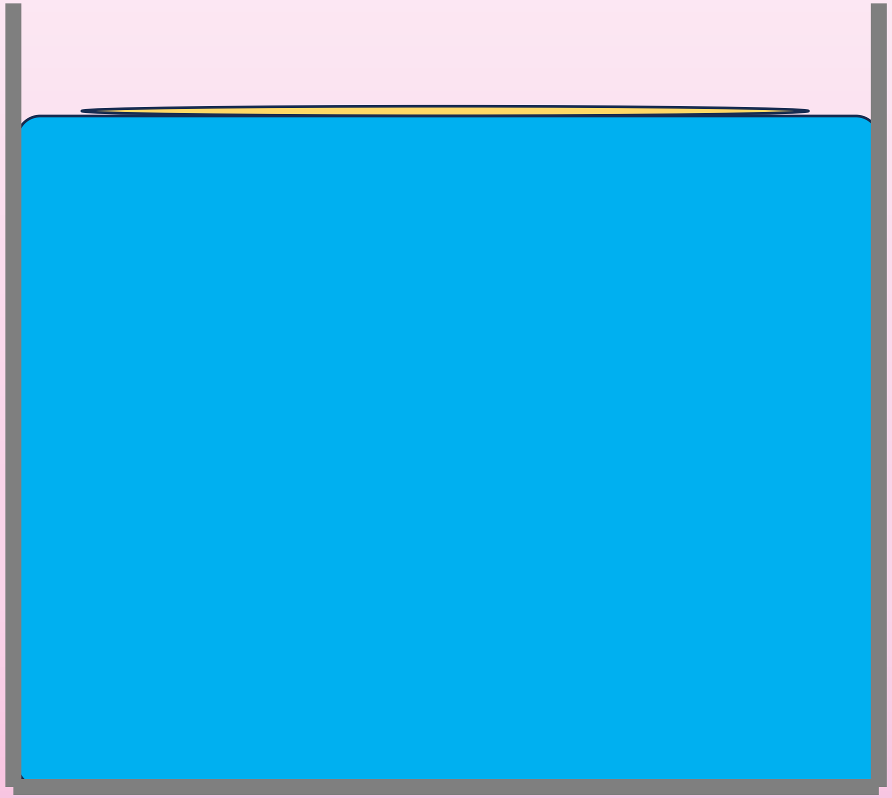
	Gas	Liquid	Solid
			
Density	Low	≈ 10^3 denser than gas	≈ 10^3 denser than gas
Compressibility	High	Low	Low
Structure	Disordered	Disordered	Highly ordered
Rigid?	No	No	Yes

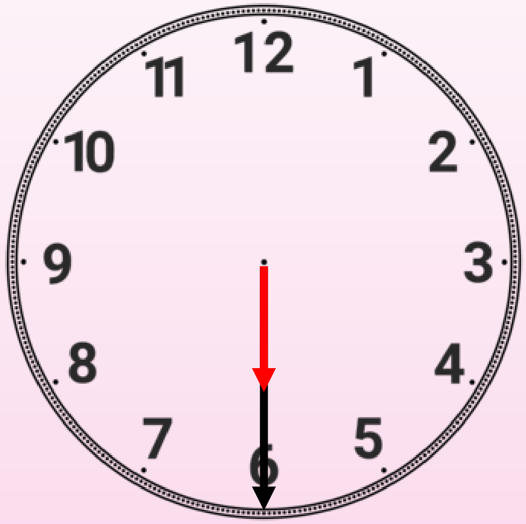
The interatomic spacing (dependent on density and somewhat compressibility) is similar for solids and liquids

Rayleigh’s oil drop measurement

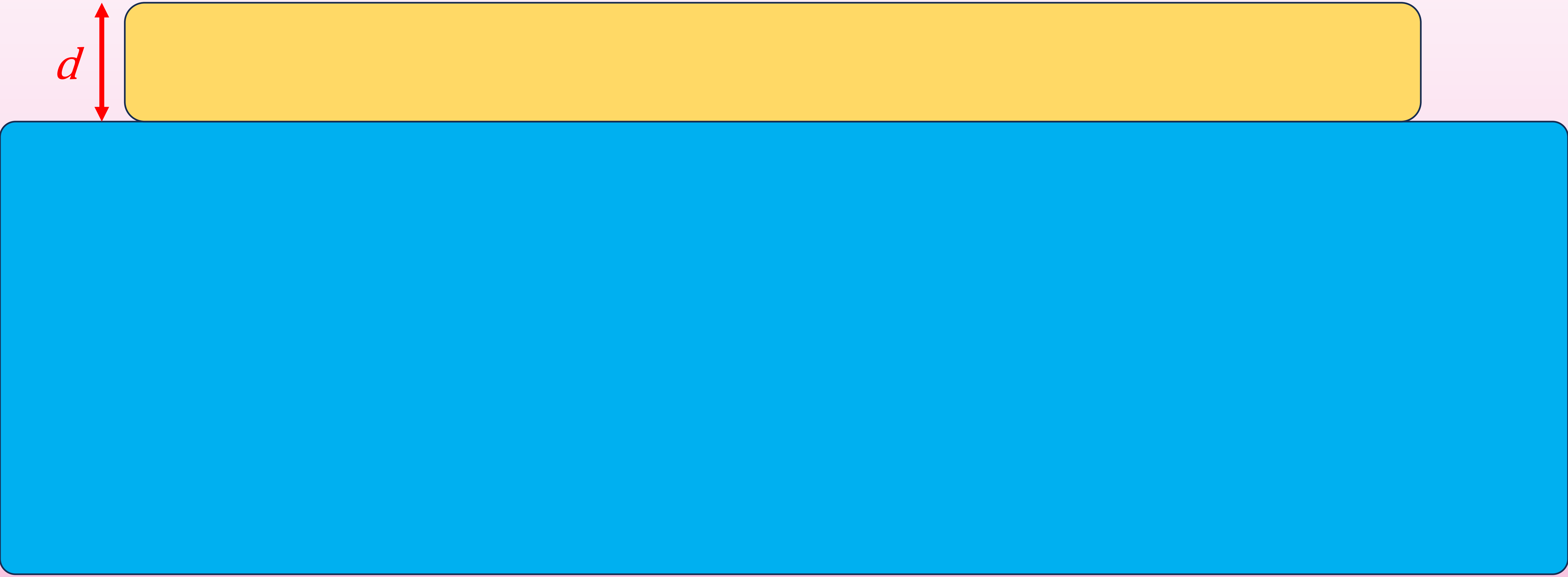


Rayleigh’s oil drop measurement

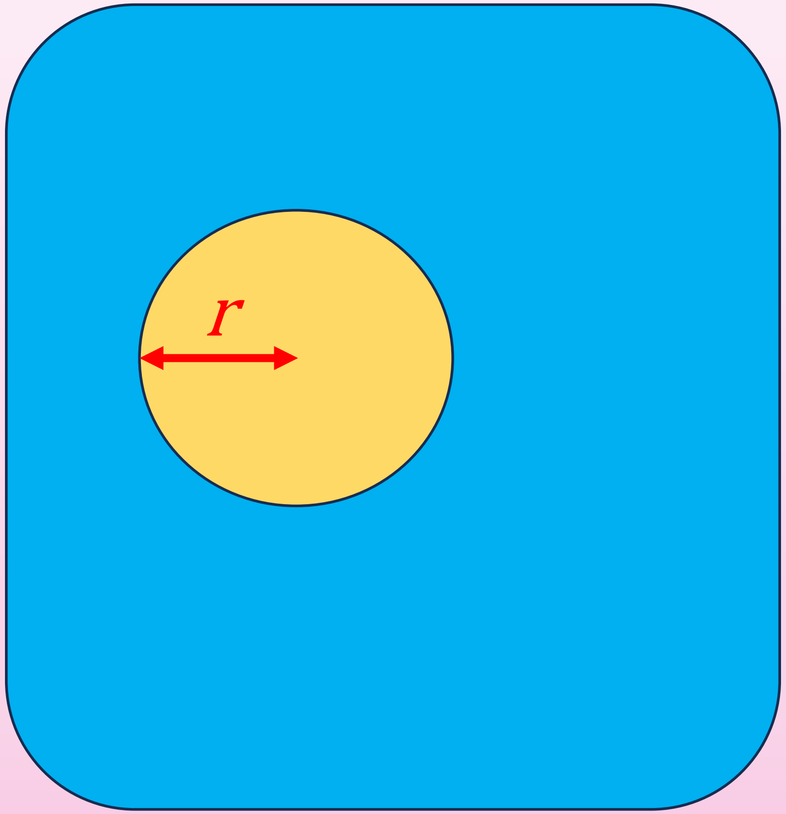




Rayleigh’s oil drop measurement



Rayleigh's oil drop measurement



By measuring the radius of the oil circle, r, the atomic distance could be related to the volume of the oil drop, V, through

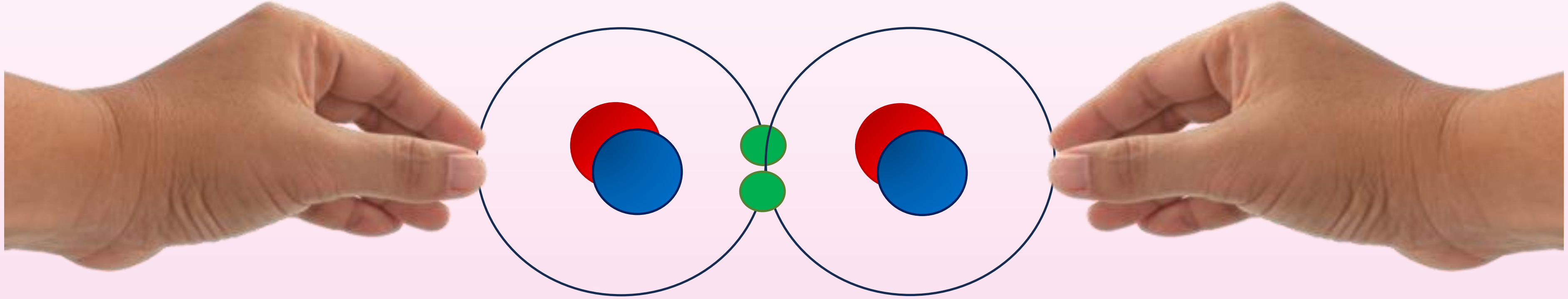
$$V = \pi r^2 d,$$

and hence

$$d = \frac{V}{\pi r^2}.$$

Rayleigh's original experiment gave ~ 1 nm

Measurement of an atom's size (latent heat)



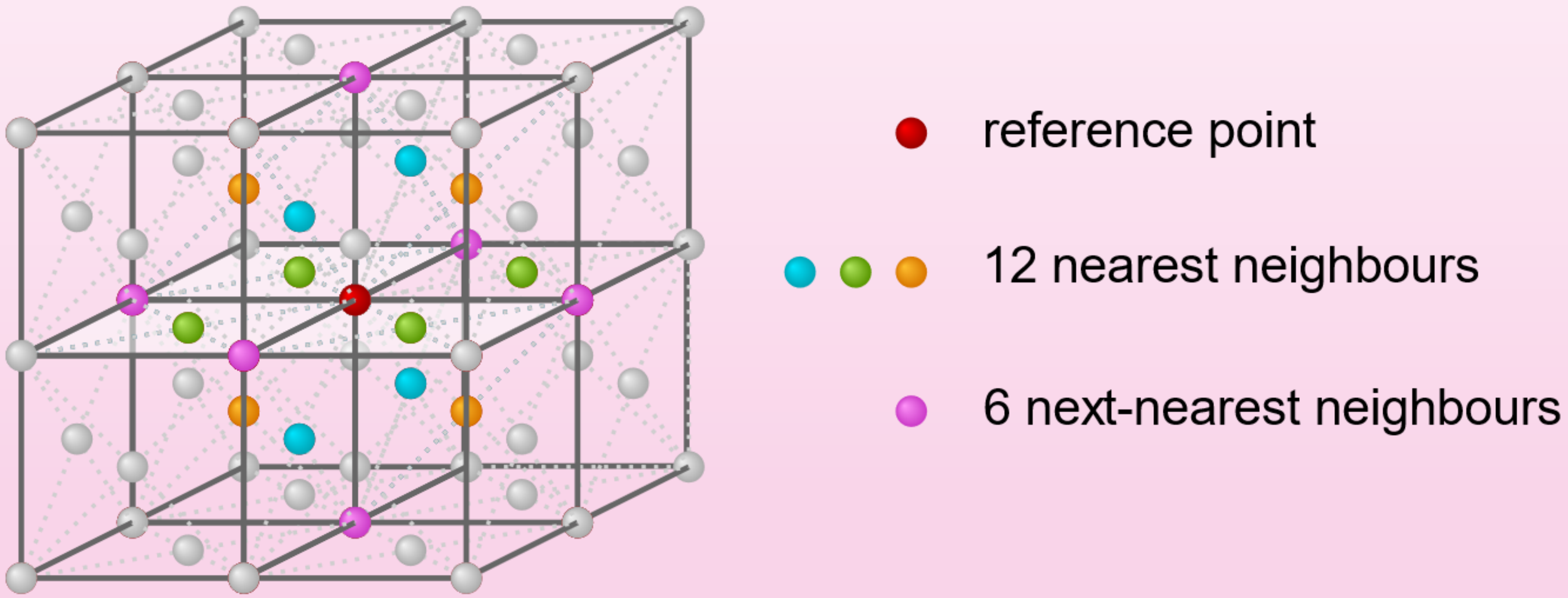
We know that there must be an attractive force keeping diatomic molecules together

If we were to separate the atoms to infinity, it would take some amount of work (U_0)

As there are two atoms, the amount of work per atom is $U_0/2$

Measurement of an atom’s size (latent heat)

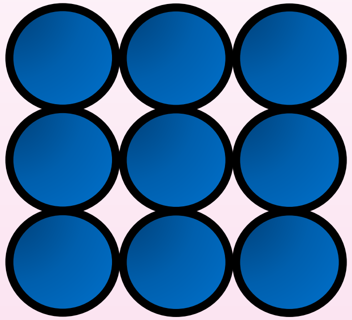
What about for a solid or liquid?



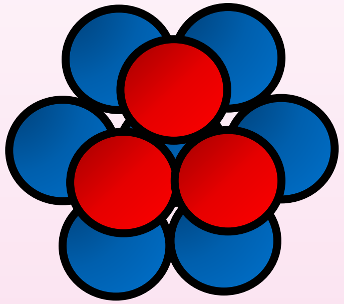
https://www.physics-in-a-nutshell.com/img/content/solid-state-physics/fcc-coordination-number-nearest-neighbours.svg

In this case, to separate atom from its nearest neighbours takes $12 \times U_0/2$

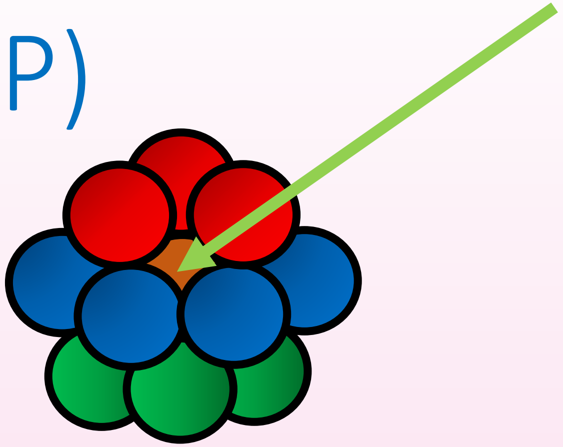
Nearest neighbours of a solid (HCP)



Inefficient!



Efficient!



Most efficient packing for spheres is a hexagonal arrangement…

Like the FCC structure, each non-surface atom has 12 nearest neighbours

Measurement of an atom's size (latent heat)

Latent heat of vaporisation, L, (J kg): the amount of heat required to completely vaporise a liquid into a gas.

$$L = 12\,U_0/2 \times \frac{atoms}{kg}$$

$$\frac{kg}{atoms} = \rho \times d^3$$

where ρ is the density of the liquid in question, and d is the interatomic spacing.

Hence, $d = \sqrt[3]{\frac{kg}{atoms \times \rho}}$

What causes force between atoms?

Electrostatic/Coulomb force? No, atoms are electrically neutral…

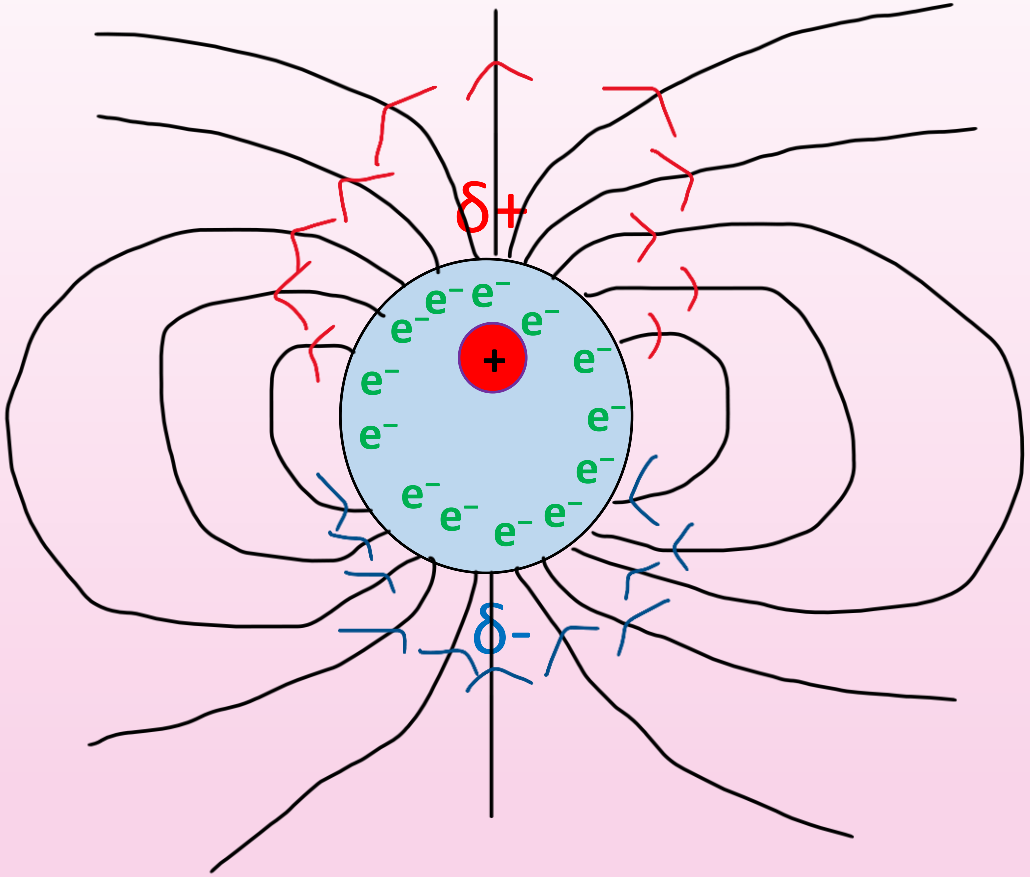
Nuclear force? No, the range of this force is ≈3 fm (3 x 10^{-15} m)…

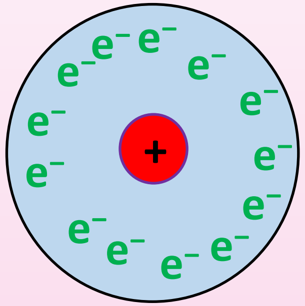
Weak force? Even worse! Range of ≈10^{-16} m

Gravitational force? Assuming lead (m ≈ 208 amu = 3.45 x 10^{-25} kg):

$$F = \frac{Gm_1m_2}{r^2} = \frac{6.67\times10^{-11}\times3.45\times10^{-25}\times3.45\times10^{-25}}{2\times10^{-10}} = 4.0 \text{ x}10^{-50}\text{N}$$

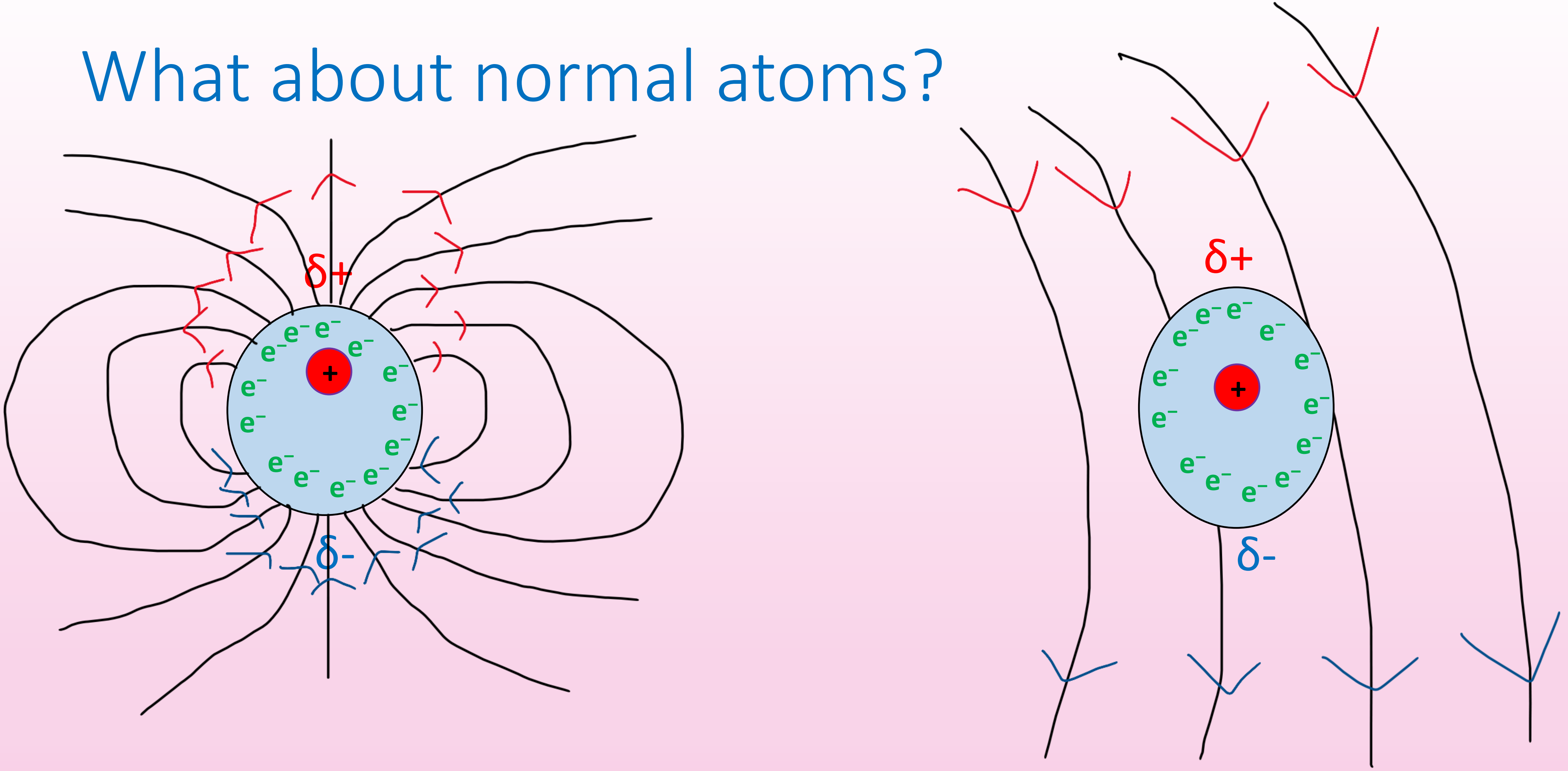
What about normal atoms?





Fluctuations in the electron cloud cause the atom to behave as an instantaneous dipole

What about normal atoms?



The second atom is polarised by the electric field and becomes a dipole as well

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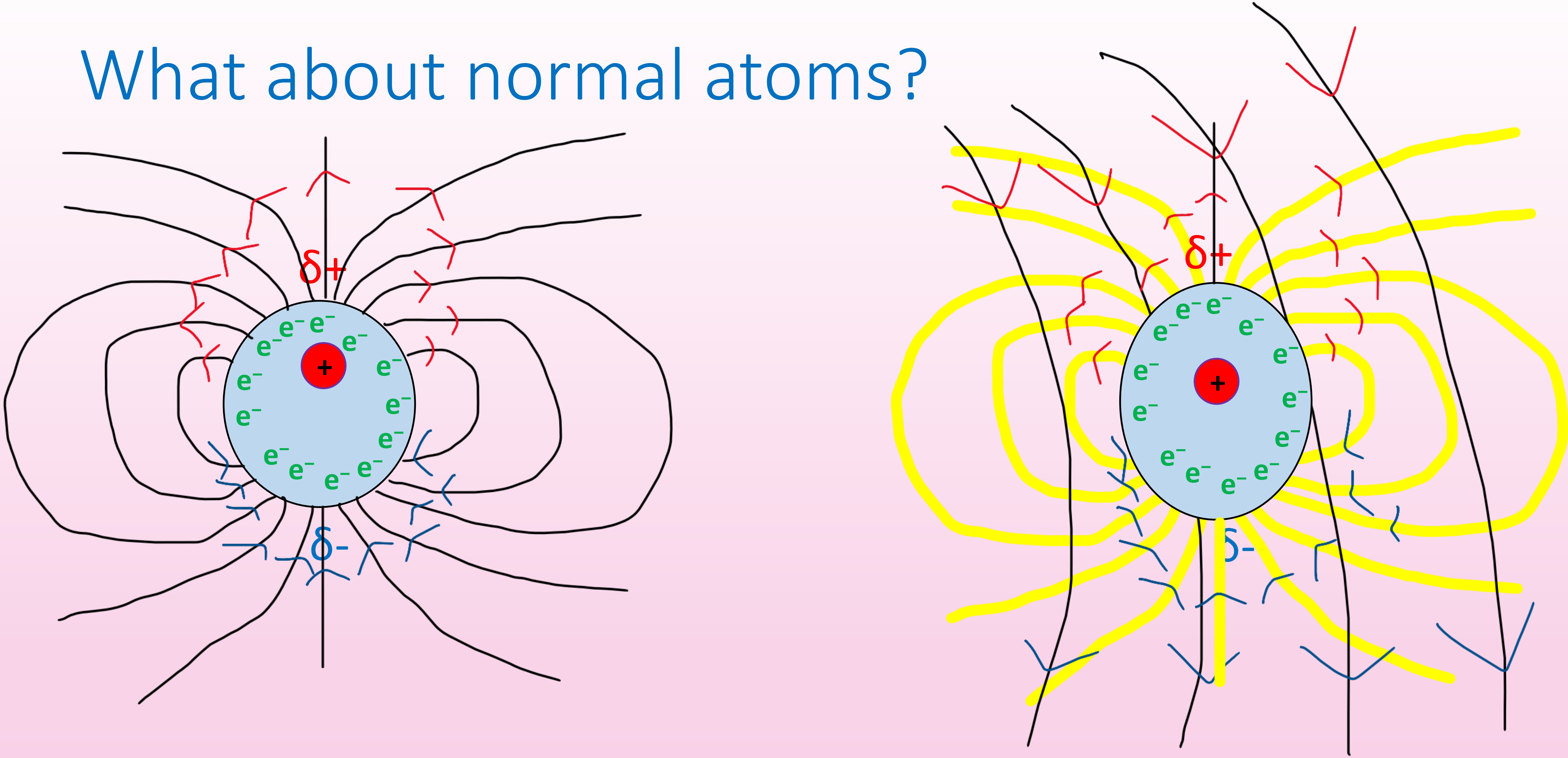

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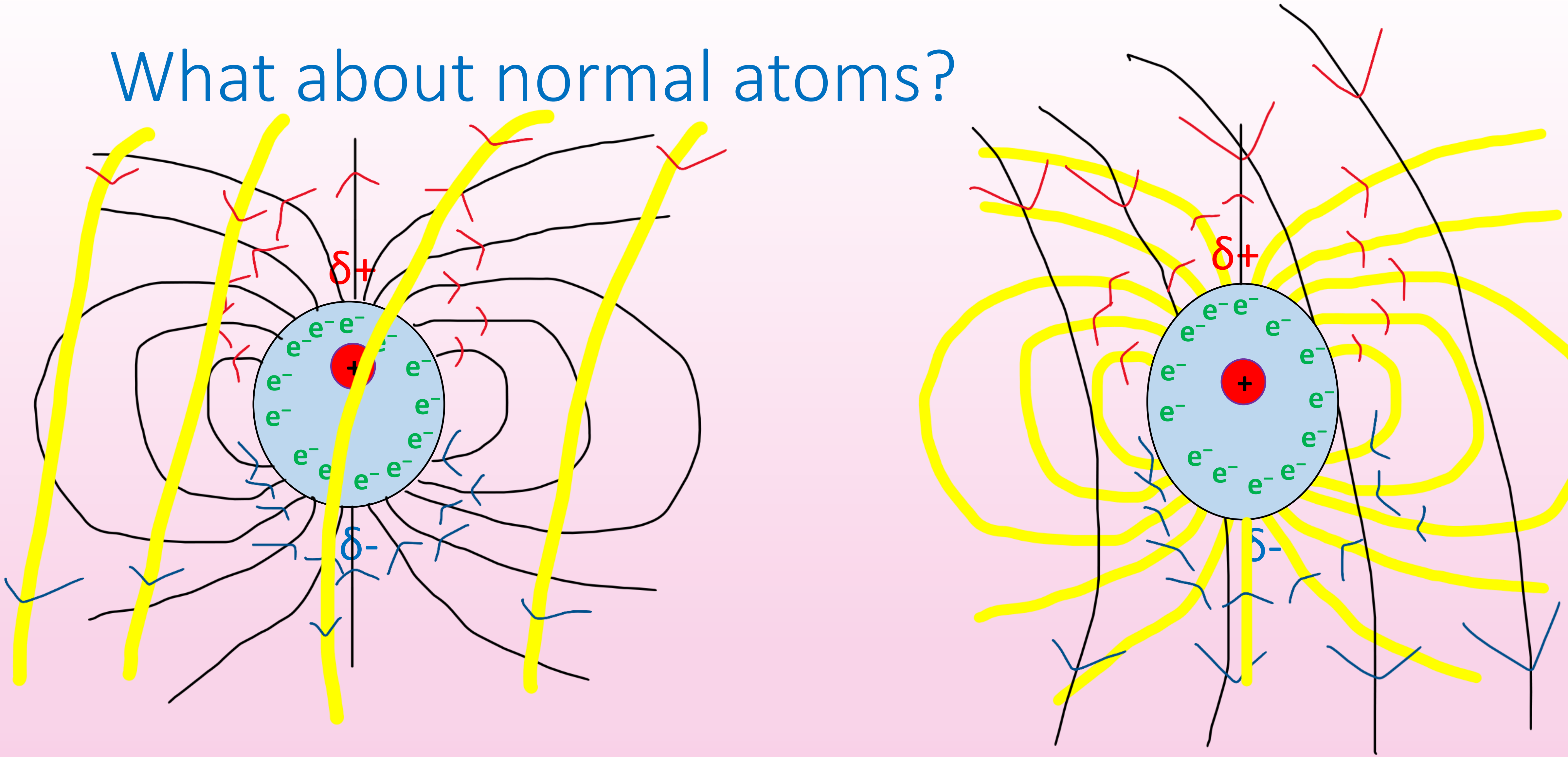


The second atom’s dipole field is experienced by the first atom and so on…

Van der Waal's force

The electric field due to a dipole goes as $|E| \propto \frac{1}{r^3}$

Hence, the size of the induced dipole in second atom goes as $\propto \frac{1}{r^3}$

Size of the induced dipole in first atom depends on strength of the dipole field and the size of the induced dipole in the second dipole

$$|V| \propto \frac{1}{r^3}\frac{1}{r^3} = \frac{1}{r^6}$$

Inter-atomic forces

Force between two atoms or molecules is positive if they repel each other, negative if they are attract each another

Van der Waals force is therefore negative, as this attracts the two atoms together.

BUT

Atoms do not collapse on top of each other -> there must be a repulsive force

Pauli exclusion principle

Particles can be split into two kinds, fermions and bosons

Fermions have half-integer spin (in units of $\hbar$) and are "antisymmetric", while bosons have integer spin and are "symmetric"

Indistinguishable fermions cannot occupy the same spatial quantum state, and hence repel one another -> approximate this as potential of form $V \propto \frac{1}{r^{12}}$

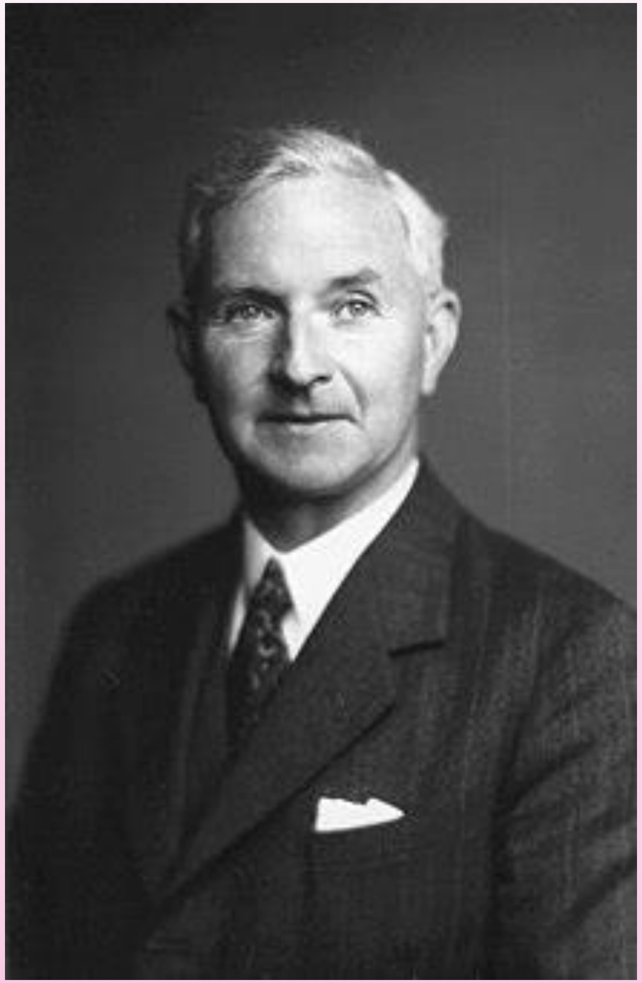
Lennard-Jones potential

First described an empirical potential between neighbouring atoms/molecules:

Repulsive

Attractive

$$V_{LJ} = \frac{A}{r^{12}} - \frac{B}{r^{6}}$$



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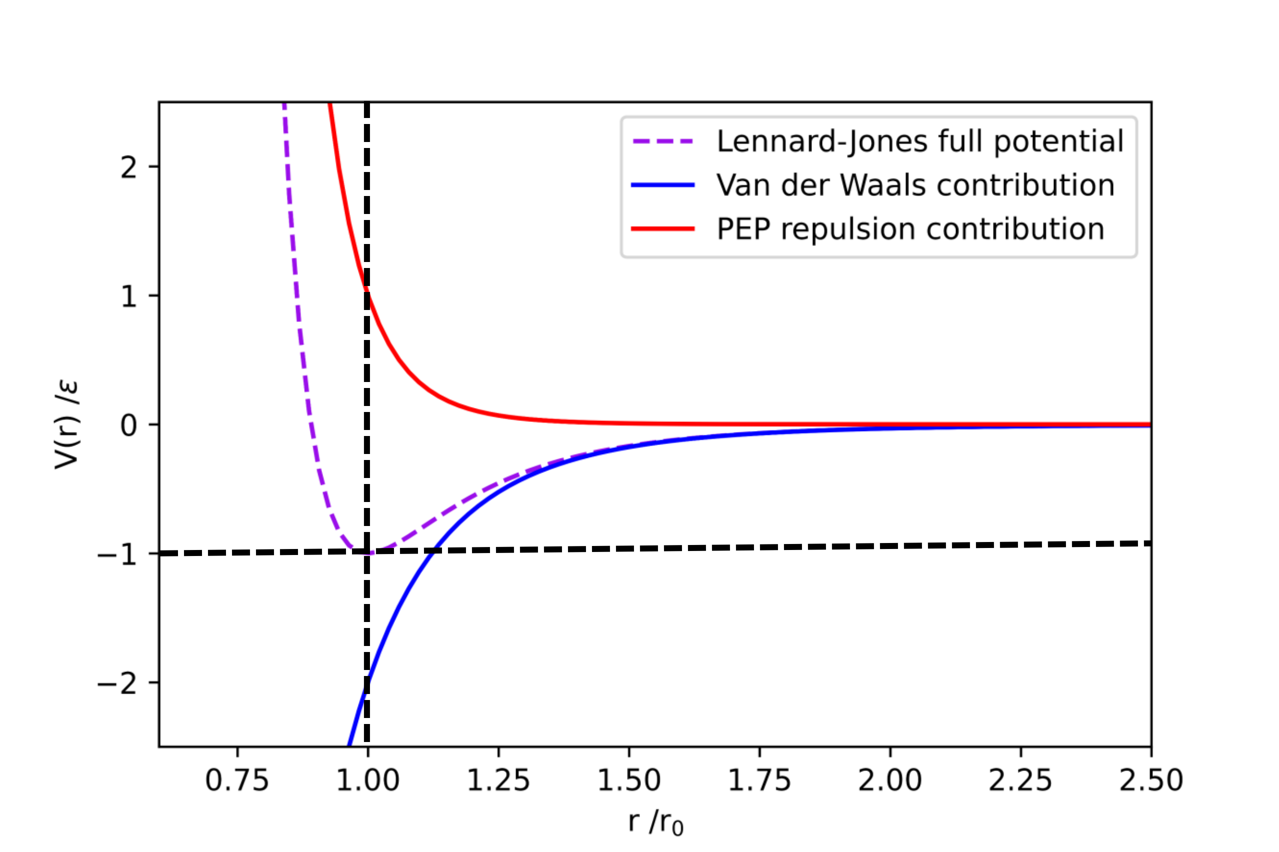

Potential is at a minimum (ε) at a distance r_0

Summary

Discussed experimental methods that can be used (and have been, historically) to investigate the size of the atom

Investigated the cause behind interatomic and intermolecular forces

Looked at a functional form to describe the potential of these force (the Lennard-Jones potential)