Phyx 320
Modern Physics

February 12, 2021

Reading: 37.1 – 37.6

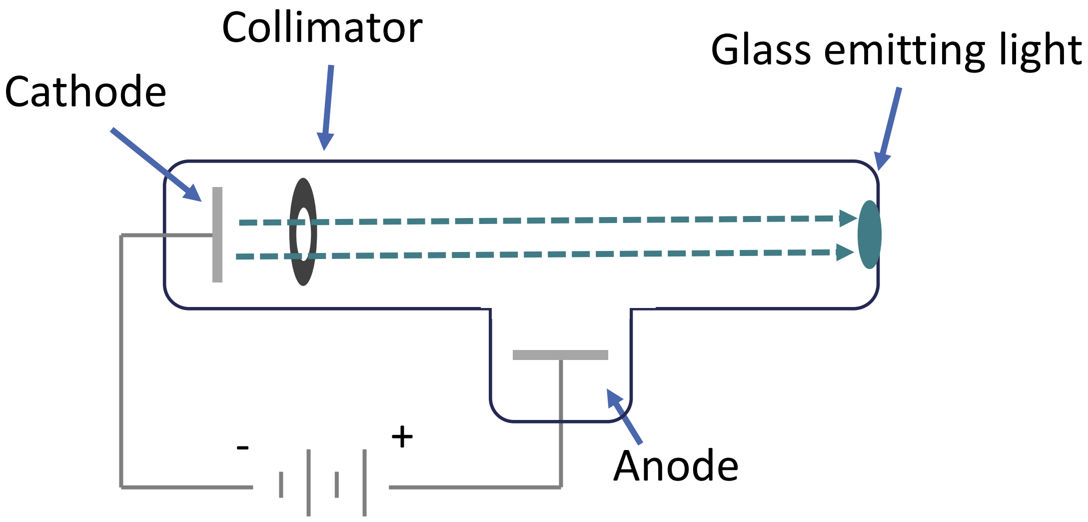
Homework #4 and Reading Reflection Due Next Tuesday 11:59 pm

Spectra and Cathode Rays

Two types of spectra
- Continuous = thermal (blackbody)
- Discrete = elemental

Hydrogen spectrum can be described by Balmer formula

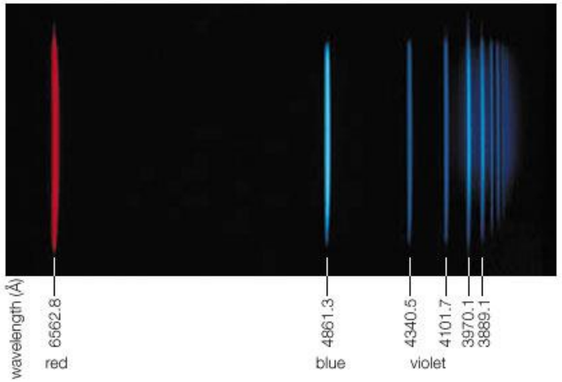
Cathode ray tube experiments brought up lots of open questions



$$\lambda = \frac{91.18\,nm}{\frac{1}{m^2} - \frac{1}{n^2}}$$

$$\mathrm{m} = 1, 2, 3, \ldots$$

$$\mathrm{n} = m + 1, m + 2, \ldots$$



Thomson's Field Experiment

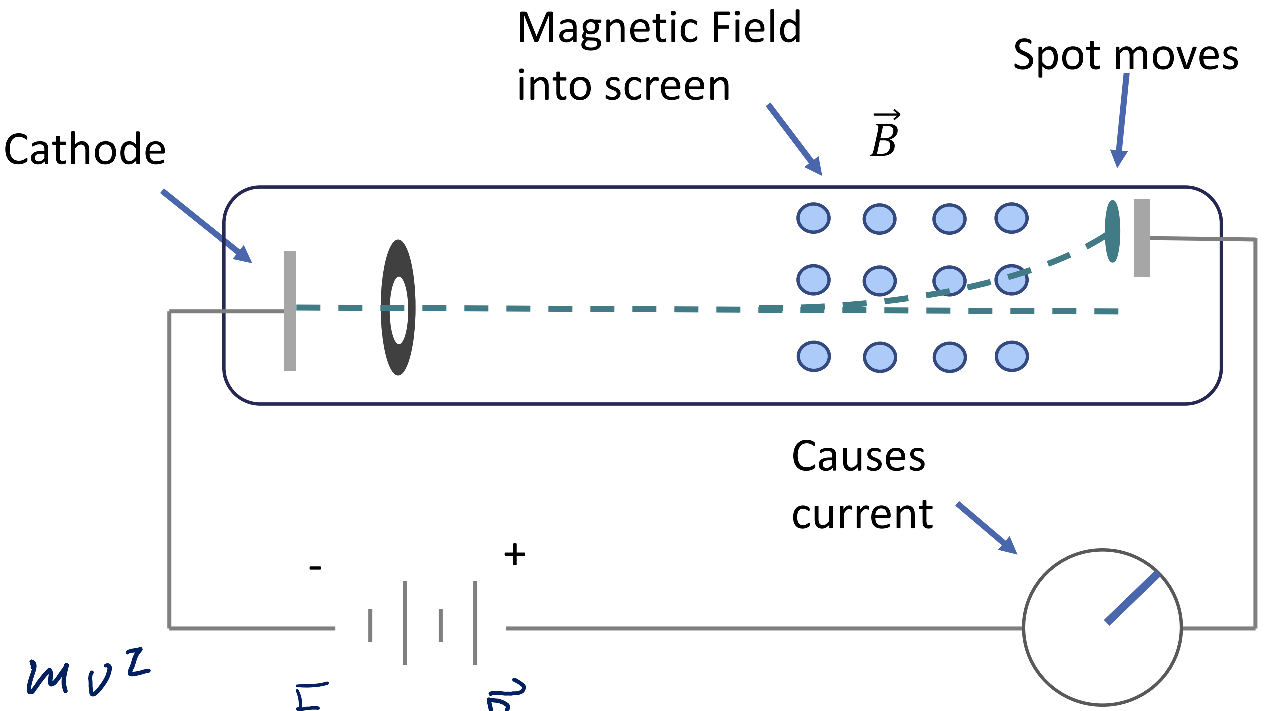
J.J. Thomson found that x-rays could ionize air molecules

- First evidence that atoms are made of multiple charged constituents

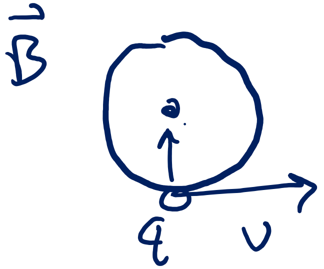
Also found that cathode rays could be bent by magnetic field

If anode is aligned with the cathode rays, then current is detected in the return line

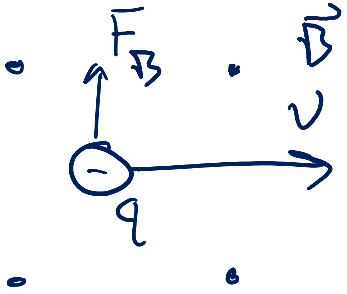
Cathode rays are negatively charged particles



$$F_B = qvB = F_{cent} = \frac{mv^2}{r}$$



$$r = \frac{mv}{qB}$$



$$\vec{F}_B = q(\vec{v} \times \vec{B})$$

$$F_B = qvB$$

Thomson’s Field Experiment

Thompson then added an electric field in addition to the magnetic field to measure the charge-to-mass ratio

$$F_B = q v B$$

$$F_E = q E$$

$$q E = q v B$$

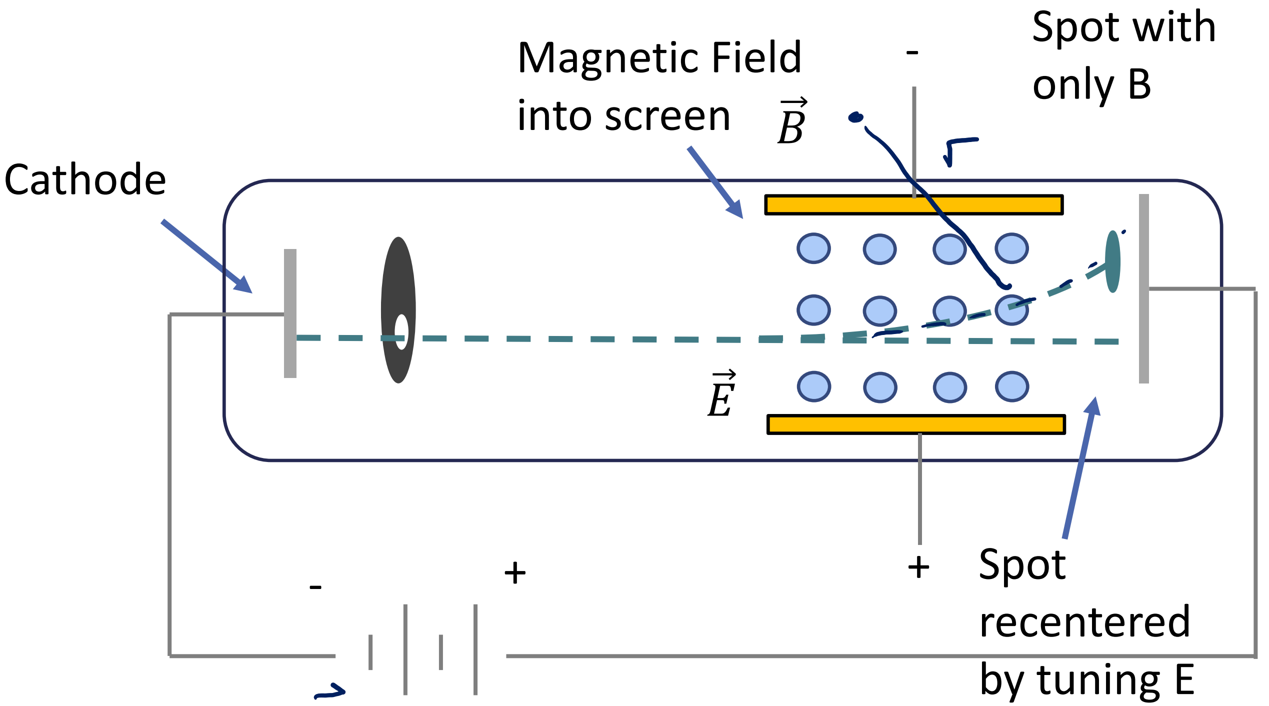
$$v = \frac{E}{B}$$

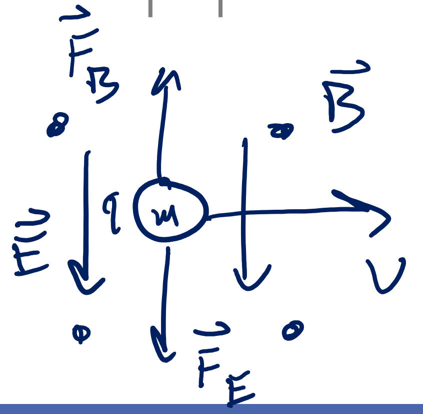
↑ measure with E+B

$$r = \frac{m v}{q B}$$

$$\frac{q}{m} = \frac{v}{r B}$$

↑ no E only B





Thomson’s Field Experiment

Measured $\frac{q}{m} = 1 \times 10^{11}\,\frac{C}{kg}$

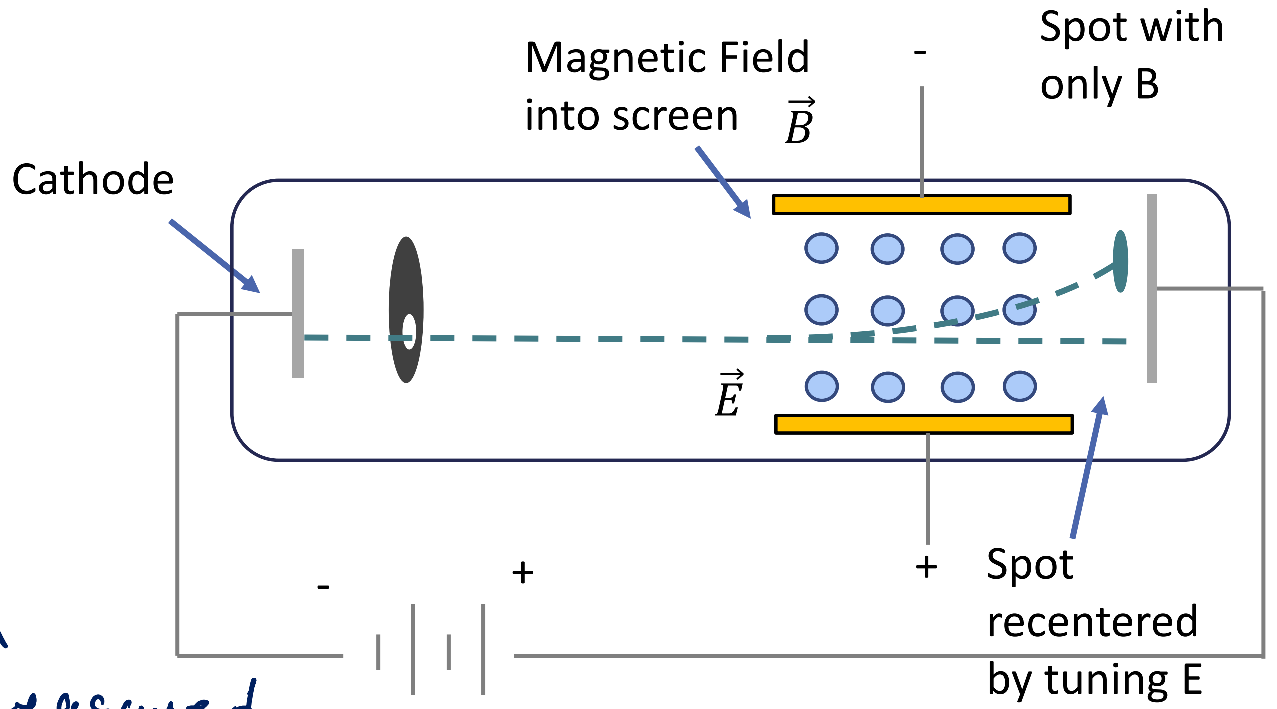
Same charge-to-mass ratio for difference cathode material

Much larger than the charge-to-mass ratio of hydrogen ions $\frac{q}{m} = 1 \times 10^{8}\,\frac{C}{kg}$

Measured
Chemistry

Cathode rays can pass through metal foil while atoms can’t

Concluded that these were subatomic particles with smaller mass than atoms called **electrons**



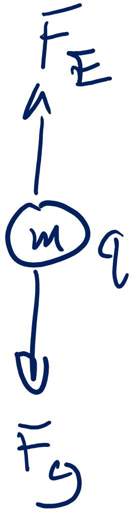
Fundamental Charge

The last experiment measured the charge-to-mass ratio, but physicists wanted to measure the charge itself

Millikan did this with fine mist of oil droplets

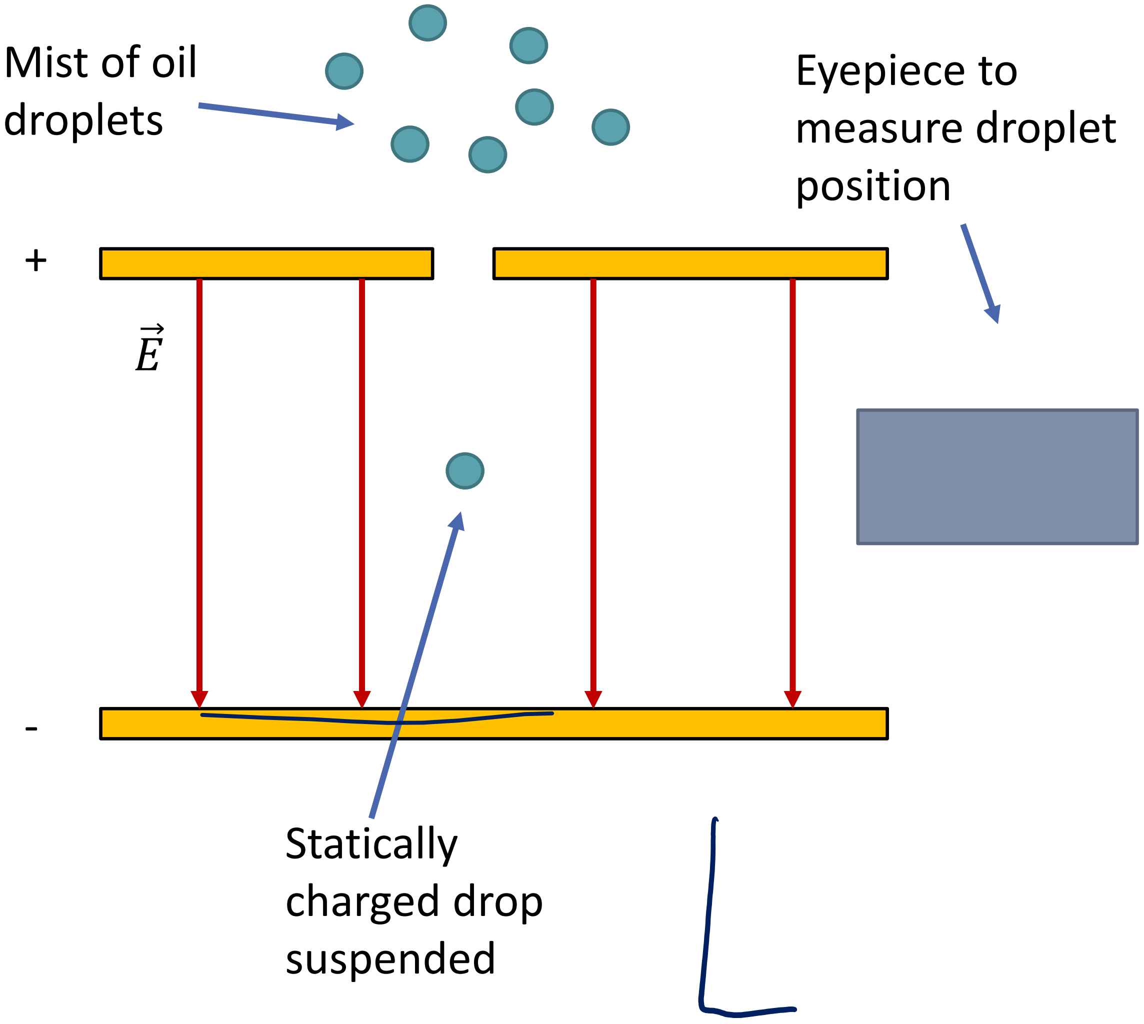
$$F_g = m_{drop} g$$

$$F_E = q_{drop} E$$



$$m_{drop} g = q_{drop} E$$

$$q_{drop} = \frac{m_{drop} g}{E}$$



Fundamental Charge

Mass measured by terminal velocity of droplet

Found both positive and negative charged droplets

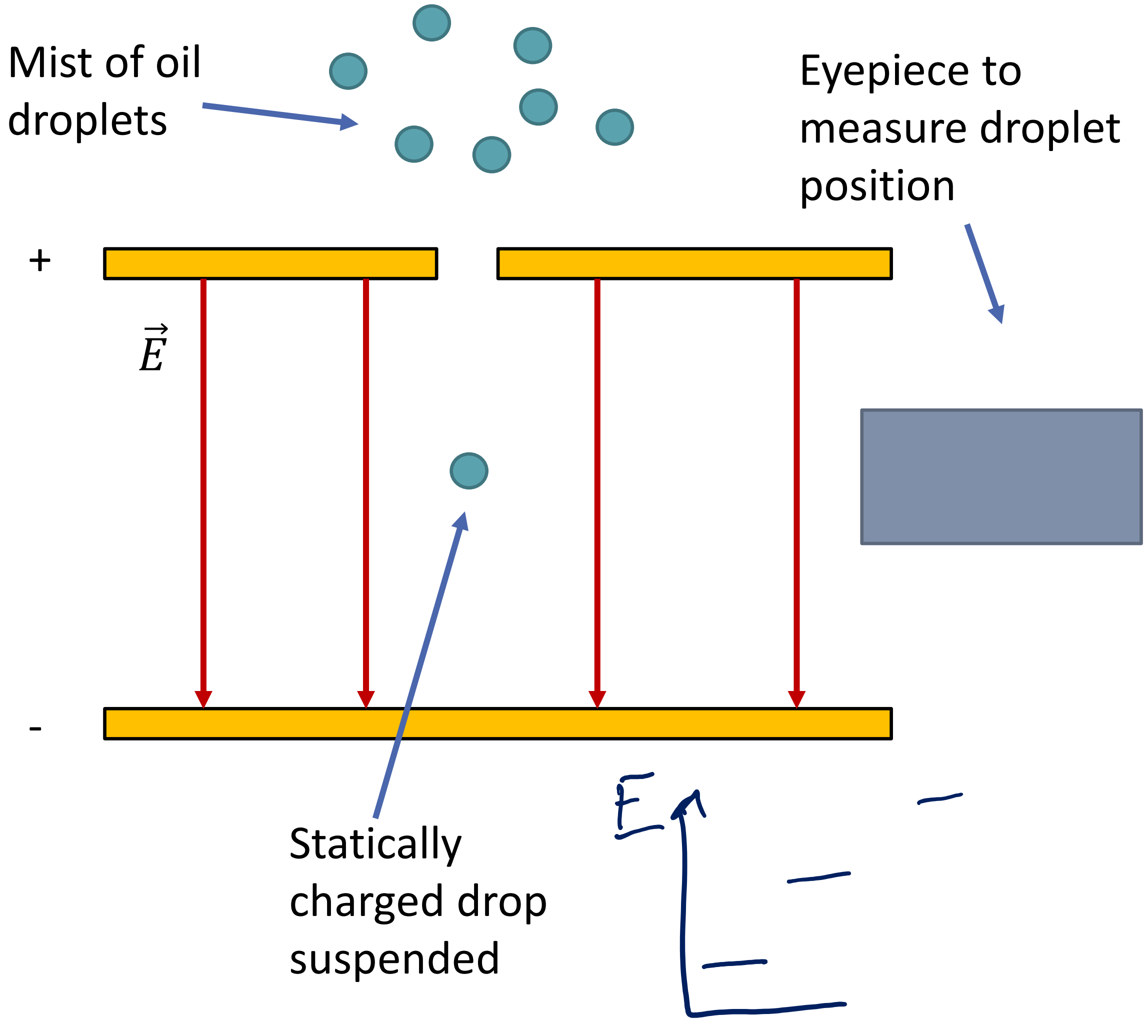
All charges were integer multiples of one number

$$e = 1.60 \times 10^{-19} C$$

This is the charge of the electron, negative droplets had extra electrons and positive less electrons

Combining this with charge-to-mass ratio gives mass of electron

$$\mathrm{m_e} = 9.11 \times 10^{-31}\ kg$$



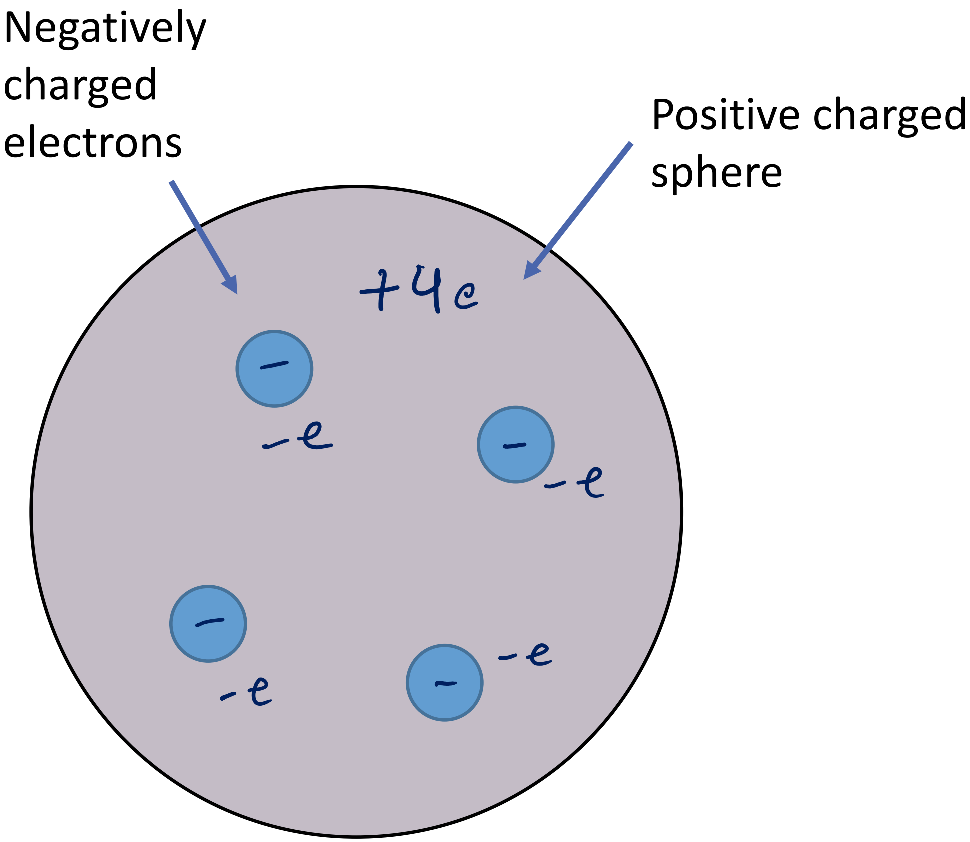
Discovery of Nucleus

With discovery of electron, atoms now have substructure

Where do the electrons live inside the atom?

Thomson used a plum-pudding model with positive charged sphere with electrons embedding in it

Charges balanced out to yield a neutral atom



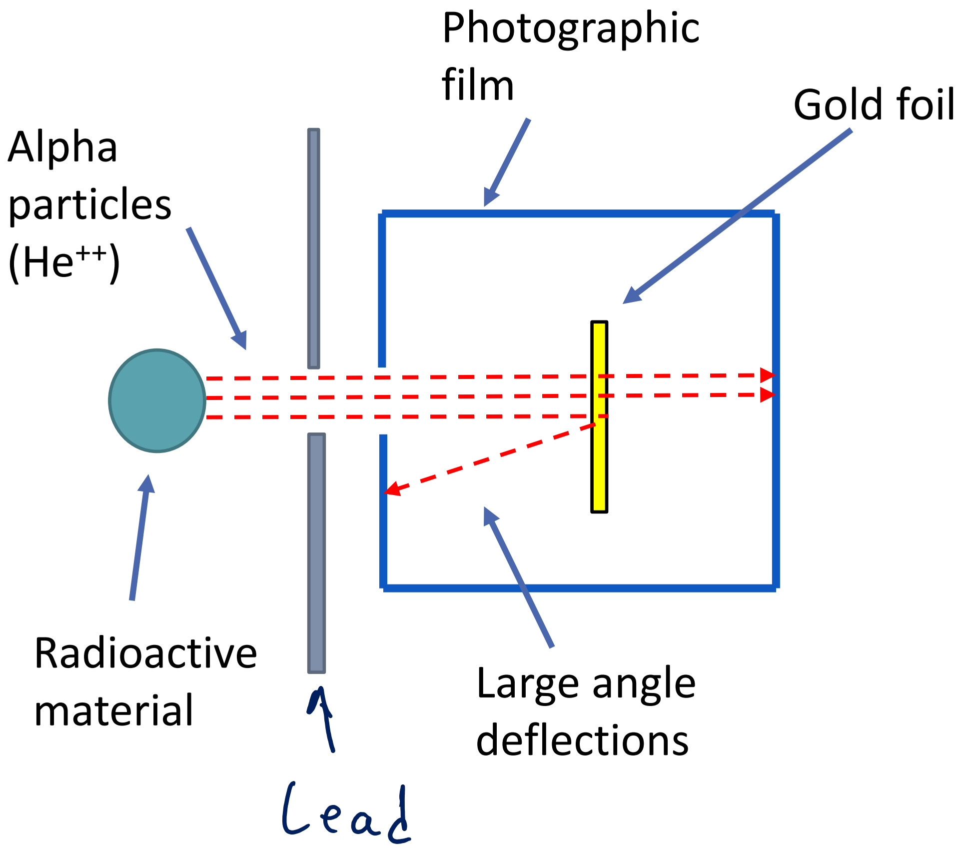
Discovery of Nucleus

It was found that radioactive material can emit electrons (beta radiation) or doubly ionized helium (alpha radiation)

Rutherford and his students set up an experiment to shoot alpha particles through gold foil

Found that some of the particles passed through the foil but other reflected at large angles

Could not be explained with plum-pudding model of the atom



Discovery of Nucleus

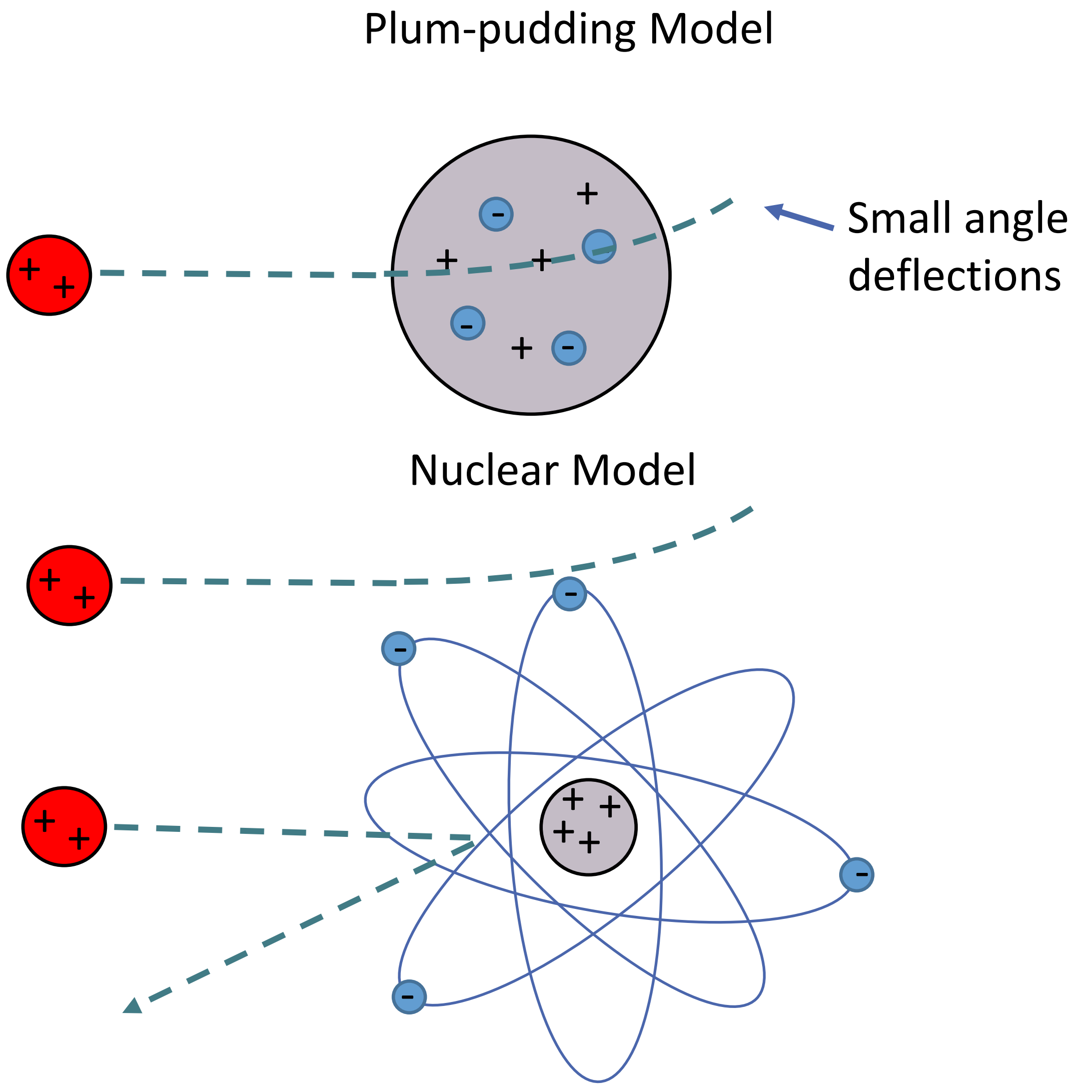
Atoms with a core of positive charge (**nucleus**) explained observations

Electrons orbit the nucleus so from large distance atoms are neutral, alpha particles don't get deflected if they aren't aligned with nucleus

If the alpha particle goes through electron cloud, then it sees highly charged nucleus and rebounds

Nucleus diameter was measured to be $\mathrm{d} \approx 1 \times 10^{-14}\ m$

atom ~ 10^{-11} m



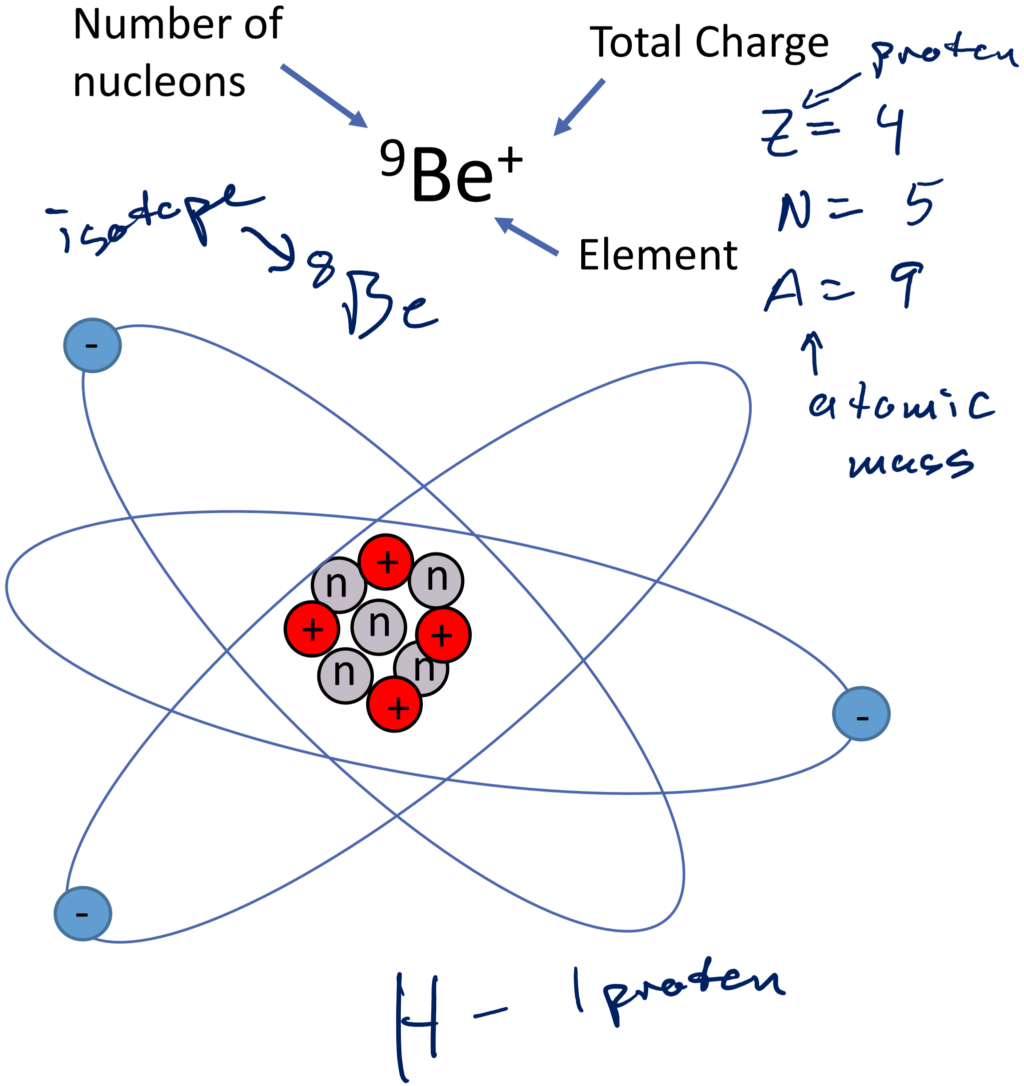
Discovery of Nucleus

Using a mass spectrometer to measure the charge-to-mass ratio of atomic ions found that the nucleus includes two types of particles (nucleons)

- Protons – positive charged (+e) nucleon, determines element
- Neutrons – neutral nucleon, approx. same mass as proton
- Electron – negative charged (-e), low mass, orbiting nucleus

Electrons can be stripped off atom to yield positively charged ions or added to yield negative charged ions

Isotopes have different number of neutrons



Discovery of Nucleus

Is this all there is to atomic physics?

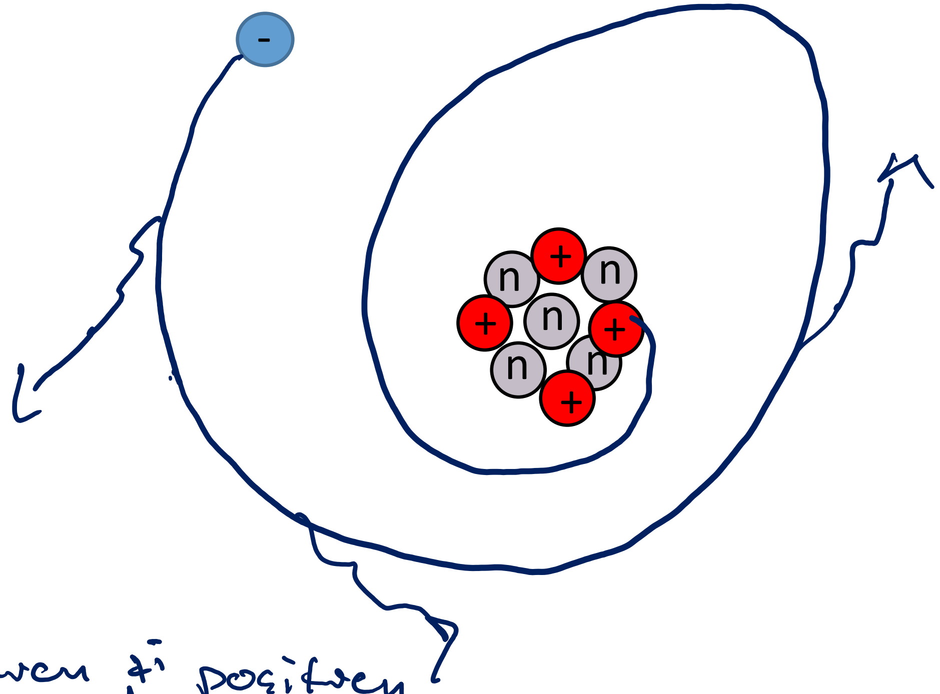
If electrons are orbiting, then they are accelerating

If their accelerating, then they emit radiation

If they emit radiation, then they loose energy

If they loose energy, they plunge into nucleus

There must be an explanation.....



electron anti positron

$e^- \rightarrow e^+$

$\mu^- \quad \mu^+$

Quiz 2 Solutions

Say a spacecraft launches from Earth at 0.3 c headed towards the star Betelgeuse. Before launch, the people on the spacecraft synchronize their clocks with the clocks on Earth. Assume that the spacecraft is instantly accelerated to 0.3 c.

1. In the Earth's frame, Betelgeuse goes supernova 2 years after the spacecraft leaves and occurs at x = 548 ly. At what x' coordinate does the supernova happen in the spacecraft's frame? At what time does it occur in the spacecraft's frame?
2. When do the observers on the Earth see the light from the supernova? When do the people on the spacecraft see it?

$v = 0.3c$

$x = 548\ ly$

$t = 2\ yr$

$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$

$\gamma = 1.05$

$x' = \gamma(x - vt)$

$c(yr) = ly$

$= (1.05)(548\ ly - 0.3c(2\ yr))$

$= 574\ ly$

$t' = \gamma\left(t - \frac{v}{c^2}x\right) = (1.05)(2\ yr - 0.3(548\ ly))$

$= -170\ yr$

Quiz 2 Solutions

$x = 548\ \text{ly}$

$t = 2\ \text{yr}$

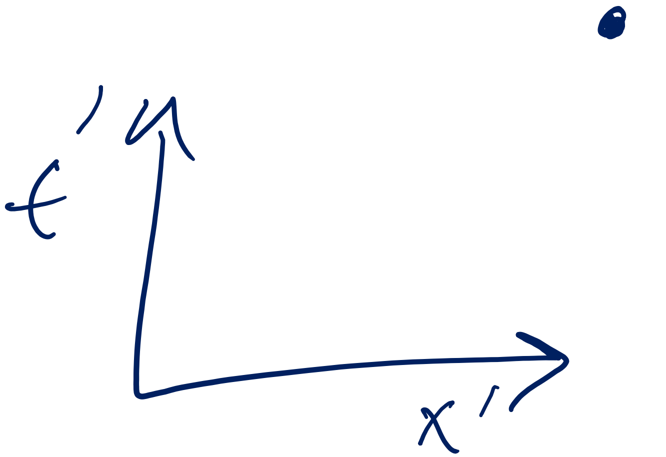
$$t_{obs} = \frac{548\ \text{ly}}{c} + 2\ \text{yr} = 550\ \text{yr}.$$

$x' = 574\ \text{ly}$

$t' = -170\ \text{yr}$

$$t'_{obs} = \frac{574\ \text{ly}}{c} - 170\ \text{yr} = 404\ \text{yr}.$$

↑ observation time



Quiz 3 Solutions

Muons (μ^-) are the heavier cousins of electrons and have a mass of 1.884×10^{-28} kg. Like electrons, muons have an antiparticle counterpart called antimuons (μ^+). If a muon and an antimuon collide, the particles annihilate each other leaving only light.

1. If we accelerate a muon to a velocity of 0.98 c, what is its momentum?
2. Let’s say we take this muon and collide it with an antimuon with the same momentum. How much energy would be released (in the form of light) during this interaction?

Quiz 3 Solutions

Homework Questions

Homework Questions