AS Physics Unit 1
1 Matter and Radiation

KS5 AS PHYSICS AQA 2450

Mr D Powell
Constituents of the atom
Proton, neutron, electron. Their charge and mass in SI units and relative units. Specific charge of nuclei and of ions. Atomic mass unit is not required. Proton number Z, nucleon number A, nuclide notation, isotopes

Stable and unstable nuclei
The strong nuclear force; its role in keeping the nucleus stable; short-range attraction to about 3 fm, very-short range repulsion below about 0.5 fm; equations for alpha decay and β- decay including the neutrino.

Particles, antiparticles and photons
Candidates should know that for every type of particle, there is a corresponding antiparticle. They should know that the positron, the antiproton, the antineutron and the antineutrino are the antiparticles of the electron, the proton, the neutron and the neutrino respectively.

Comparison of particle and antiparticle masses, charge and rest energy in MeV. Photon model of electromagnetic radiation.

Knowledge of annihilation and pair production processes and the respective energies involved. The use of \( E = mc^2 \) is not required in calculations.
What am I thinking of?
### Inside the atom/ Constituents of the atom p4

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| **K** | ▪ What is a proton, neutron, electron. Their charge and mass in SI units and relative units.  
▪ Specific charge of nuclei and of ions.  
▪ Atomic mass unit is not required. Proton number Z, nucleon number A, nuclide notation, isotopes |
| **S** | ▪ Being able to manipulate formulae of elements and isotopes from their symbols alone and work out numbers of proton etc.. From the symbols. |
| **U** | ▪ Why isotopes have different numbers of neutrons.  
▪ Why is the atom structured the way it is.  
▪ How can we probe the nucleus with small particles. |
Periodic Table

- The periodic table is a way of arranging elements on the basis of chemical and physical properties.
- It runs in order of proton number and all atoms of an element have the same number of protons.
- Isotopes of elements can have different masses to elements as they have extra neutrons.
Periodic Table

- Look at this image and a real copy of the table and get familiar with the elements.

- **B**oron, **C**arbon, **N**itrogen, **O**xygen, **F**luorine, **Ne**on, **Al**uminium, **Si**licon, **P**hosphorus, **S**ulphur, **Cl**orine, **Ar**gon

- **Ga**llium, **Ge**nerium, **As**en, **Se**lenium, **Br**omine, **K**rypton

- **In**dium, **Sn**in, **Sb**antimony, **Te**llurium, **I**odine, **Xe**non

- **Tl**cury, **Pb**lead, **Bi**ismuth, **Po**lonium, **At**astatine, **Rn**adon

- Relative Atomic Mass (1)

- Relative Atomic Mass (2)

- **s**, $^{11}\text{B}$ (80.1%) and $^{10}\text{B}$ (19.9%). The $^{11}\text{B}$ and $^{10}\text{B}$ and traditionally exp...
What is specific charge?

This is the amount of charge per kilogram of matter....

This is the specific charge on a proton....

Just be clear if you are dealing with items with different masses and charges....

1. Nucleus
2. Ion
3. Particle
Quick Questions

1. What is charge measured in?
2. What is the mass of a proton?
3. What is the mass of a neutron?
4. What is the charge on an electron?
5. What is the mass of a Helium nucleus?
6. What is the specific charge of a Helium nucleus?
7. What are units of specific charge?
8. What does the term “A” refer to on the periodic table?
9. What does the term “Z” refer to....
10. What are nucleons?
What am I thinking of?

pull  push

[picture of a muscular arm]

[picture of a car]

[radioactive symbol]
### Stable and unstable nuclei p6

<table>
<thead>
<tr>
<th>K</th>
<th>Learn the equations for $\alpha$-decay and $\beta$-decay including the neutrino.</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Be able to explain alpha &amp; beta decay</td>
</tr>
<tr>
<td></td>
<td>Be able to draw a graph for the strong force and explain it.</td>
</tr>
<tr>
<td>U</td>
<td>Understand the ideas behind the strong nuclear force;</td>
</tr>
<tr>
<td></td>
<td>its role in keeping the nucleus stable;</td>
</tr>
<tr>
<td></td>
<td>short-range attraction to about 3 fm,</td>
</tr>
<tr>
<td></td>
<td>very-short range repulsion below about 0.5 fm;</td>
</tr>
</tbody>
</table>
You may remember this from GCSE studies. Can you talk about why this is using the ideas from last lesson...
Alpha Decay....

α decay

<table>
<thead>
<tr>
<th>neutron number N</th>
<th>Z/2</th>
<th>N-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Alpha particles tracks

2 fewer protons
2 fewer neutrons

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Alpha Particle Decay

Radioactive Uranium 238
146n 92p 92e
(parent)

Alpha Decay

Radioactive Thorium 234
144n 90p 90e
(daughter)

More Stable

Back

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**Beta Decay...**

<table>
<thead>
<tr>
<th>Neutron number $N$</th>
<th>Proton number $Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>$Z$</td>
</tr>
<tr>
<td>$Z+1$</td>
<td>$N-1$</td>
</tr>
</tbody>
</table>

- **$\beta^-$ decay**
- 1 more proton
- 1 less neutron
Beta Particle Decay

Radioactive Iodine 131
78n 53p 53e (parent)

Beta Decay

More Stable

Radioactive Thorium 131
77n 54p 54e (daughter)
Carbon Dating

\[ ^{14}_{7}N + n \rightarrow ^{14}_{6}C + p \]

\[ ^{14}_{6}C \xrightarrow{\text{beta decay}} ^{14}_{7}N + e^{-} \]

Here is a good example of capture of a neutron into the nucleus followed by decay back again via a beta minus process.
## Decay Modes of Carbon

### TASK: Create a Model Map. decay modes & $T_{1/2}$ times

| symbol | $Z(p)$ | $N(n)$ | isotopic mass (u) | half-life | decay mode(s) | daughter isotope(s)
|--------|--------|--------|------------------|----------|---------------|-------------------|
| $^8\text{C}$ | 6      | 2      | 8.037675(25)     | $2.0(4) \times 10^{-21}$ s | $2p$ | $^6\text{Be}$
| $^9\text{C}$ | 6      | 3      | 9.0310367(23)    | $126.5(9)$ ms | $\beta^+$ (60%) | $^9\text{B}$
|          |        |        |                  |          | $\beta^+$, $p$ (23%) | $^8\text{Be}$
|          |        |        |                  |          | $\beta^+$, $\alpha$ (17%) | $^5\text{Li}$
| $^{10}\text{C}$ | 6      | 4      | 10.0168532(4)    | $19.290(12)$ s | $\beta^+$ | $^{10}\text{B}$
| $^{11}\text{C}$ | 6      | 5      | 11.0114336(10)   | $20.334(24)$ min | $\beta^+$ | $^{11}\text{B}$
| $^{12}\text{C}$ | 6      | 6      | 12 exactly       |          | Stable | Stable
| $^{13}\text{C}$ | 6      | 7      | 13.0033548378(10)|          | Stable | Stable
| $^{14}\text{C}$ | 6      | 8      | 14.003241989(4)  | $5.70(3) \times 10^3$ years | $\beta^-$ | $^{14}\text{N}$
| $^{15}\text{C}$ | 6      | 9      | 15.0105993(9)    | $2.449(5)$ s | $\beta^-$ | $^{15}\text{N}$

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Gamma Decay...

\[ \gamma \text{ decay} \]

\[
\begin{array}{|c|c|c|}
\hline
\text{proton number } Z & & \\
\hline
\text{neutron number } N & Z & N \\
\hline
\end{array}
\]

same protons and neutrons
Neutrinos are thought to be the most numerous particle in the universe and are thought to outnumber protons and neutrons by a factor of around 1,000,000,000 (there are 100 in every cubic cm of space).

It is thought that the neutrino has close to no mass and carry no charge which leads to the difficult task of detecting them.

The first neutrinos were created at the time of the ‘Big Bang’ and are continually being produced all the time through Beta radiation.

Like with all the other fundamental particles the neutrino has an anti-neutrino and both interact very weakly with other particles (which is also why they are so difficult to detect).

The main difference between the neutrino and the anti-neutrino is in fact it’s direction of spin.
The Neutrino..

How where they first predicted?

Wolfgang Pauli saw that beta radiation did not give off any fixed energy value, he suggested the Neutrino was emitted with the high energy electron to keep the energy level in Beta decay as shown below;

These lines represent the energy levels each beta radiation was giving out

The gap between the energy of the beta radiation and the constant energy value is the amount of energy the neutrino must take up to agree with the ‘conservation of energy’ laws.
‘Missing’ energy in beta decay

Beta decay of strontium–90

- Rest energy
- Strontium–90
  - 0.546 MeV
  - 38 protons, 52 neutrons
- Yttrium–90
  - 39 protons, 51 neutrons

\( \beta^- \)
Energy Level ideas.

Beta decay of strontium–90, including antineutrino emission

rest energy

strontium–90

0.546 MeV

yttrium–90

energy $E_\beta$

energy 0.546 MeV – $E_\beta$

$\beta^-$

$\bar{\nu}$
Where does it come from?

The strong force actually acts between quarks which are found inside nucleons.

It's the strong force that causes nucleons to attract.

The carrier of this force is the gluon.

The force ensures that the protons and neutrons in the nucleus of the atom stay together without flying apart. The nucleus of the atom is formed in this way.

This force is so strong that it almost causes the protons and neutrons within the nucleus to bind to each other.

This is why the minute particles that possess this force are called "gluon" meaning "glue" in Latin.
Forces combined

- The overall graph is a combination of electrostatic repulsion and the strong force.

Basic: Take a note of this information of the two forces.

Harder: Can you combine the two ideas on one graph.
What am I thinking of?
<table>
<thead>
<tr>
<th>Panel</th>
<th>Questions</th>
</tr>
</thead>
</table>
| **K** | - What is a photon?  
       | - What is the energy of a photon?  
       | - How the Planck constant relates to Energy: $E = \frac{hc}{\lambda}$ |
| **S** | - Calculate how many photons a light source emits in a second? |
| **U** | - Where the energy a photon has comes from?  
       | - Where do photons come from and fit into the world of particle physics? |
Question....

Can you explain what this means....

[Graphs showing repulsive and attractive forces vs. separation]
Which is laser light & why?
Photons a General Description...

Under the photon theory of light, a photon is a discrete bundle, packet or quantum of electromagnetic or light energy.

Photons are always in motion and, in a vacuum, have a constant speed of light to all observers of $c = 2.998 \times 10^8 \text{ ms}^{-1}$.

Photons have zero mass but carry both energy and momentum, which are also related to the frequency $f$ and wavelength $\lambda$ of the electromagnetic wave by

$$E = hf = hc/\lambda$$

They can be destroyed/created when radiation is absorbed/ emitted. They can have particle-like interactions (i.e. collisions) with electrons and other particles. (will look at this later)
More on Photons...

- The photon is an elementary particle, despite the fact that it has no mass.
- It cannot decay on its own, although the energy of the photon can transfer (or be created) upon interaction with other particles.
- Photons are electrically neutral and are one of the rare particles that are identical to their antiparticle, the antiphoton.
- Not needed for AS - Photons are spin-1 particles (making them bosons), which means that their energy is polarised in a direction. This feature is what allows for polarisation of light. (i.e. TV aerials)
Summary

A laser produces **Light Amplification by the Stimulated Emission of Radiation**.

- Energy is pumped into the atoms to excite them into a **metastable state**. This is a state that has a long lifetime $\approx 10^{-3}$ s compared with $\approx 10^{-8}$ s for normal excited states.
- The number of excited atoms builds up until most of the atoms are in an excited state and relatively few in the ground state. This is called a **population inversion**.
- An incident photon with the correct frequency **stimulates** the atoms so that the excited electrons all move to a lower level at the same instant.
- The emitted photons are all in the same direction and have the same phase as the incident photon and so are **coherent**.
- Because all the emissions occur at the same time and in the same direction there is a **high intensity beam in a particular direction**.

\[
E = hf \\
P = nhf \\
\text{n = number of photons arriving per second}
\]
Wavelength examples...

- A **ruby laser** is a solid-state laser and emits at a wavelength of 694 nm. Other lasing mediums can be selected based on the desired emission wavelength (see table below), power needed, and pulse duration. Some lasers are very powerful, such as the CO$_2$ laser, which can cut through steel. The reason that the CO$_2$ laser is so dangerous is because it emits laser light in the infrared and microwave region of the spectrum. Infrared radiation is heat, and this laser basically melts through whatever it is focused upon. Other lasers, such as diode lasers, are very weak and are used in today’s pocket laser pointers. These lasers typically emit a red beam of light that has a wavelength between 630 nm and 680 nm. Lasers are utilised in industry and research to do many things, including using intense laser light to excite other molecules to observe what happens to them.

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argon fluoride (UV)</td>
<td>193</td>
</tr>
<tr>
<td>Krypton fluoride (UV)</td>
<td>248</td>
</tr>
<tr>
<td>Xenon chloride (UV)</td>
<td>308</td>
</tr>
<tr>
<td>Nitrogen (UV)</td>
<td>337</td>
</tr>
<tr>
<td>Argon (blue)</td>
<td>488</td>
</tr>
<tr>
<td>Argon (green)</td>
<td>514</td>
</tr>
<tr>
<td>Helium neon (green)</td>
<td>543</td>
</tr>
<tr>
<td>Helium neon (red)</td>
<td>633</td>
</tr>
<tr>
<td>Rhodamine 6G dye (tunable)</td>
<td>570-650</td>
</tr>
<tr>
<td>Ruby (CrAlO$_3$) (red)</td>
<td>694</td>
</tr>
<tr>
<td>Nd:Yag (NIR)</td>
<td>1064</td>
</tr>
<tr>
<td>Carbon dioxide (FIR)</td>
<td>10600</td>
</tr>
</tbody>
</table>
Obi Wan or Obi Non!

• What a great use for a LASER

• Great idea for cutting metals, fighting and generally chopping up any undesirables!

• However, what the Jedi Knights did not reckon on is $E = hf$.

TASK

• Can you describe using a Quantum Physics explanation why this is a load of “Hoki Magic” and what would happen if light could behave this way?
Calculations & Maths

The known constants for these calculations are always;

\[ h = 6.63 \times 10^{-34} \text{Js} \]

\[ c = 3.00 \times 10^8 \text{ ms}^{-1} \]

- Using our formulae of \( E = hf \) or since \( c = f \lambda \), \( f = c/\lambda \) we could say for neatness and simplicity that;

\[ E = \frac{hc}{\lambda} \]

- Try working out the energies for different frequencies of visible light to test out your skills. You should get a range of answers i.e. \( 3 \times 10^{-19} \text{J} \). Try 350nm, 590nm, 700nm

350nm = 5.68 x 10^{-19}J
590nm = 3.37 x 10^{-19}J
700nm = 2.84 x 10^{-19}J
What am I thinking of....

R-Thalidomide (sleep-inducing)

S-Thalidomide (teratogenic)
### Particles & Antiparticles p10

<p>| | |</p>
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| **K** | - That for every type of particle, there is a corresponding antiparticle.  
        - The positron, the antiproton, the antineutron and the antineutrino are the antiparticles of the electron, the proton, the neutron and the neutrino respectively. |
| **S** | - Comparison of particle and antiparticle masses, charge and rest energy in MeV. |
| **U** | - The annihilation process and pair production processes and the respective energies involved. The use of $E = mc^2$ is not required in calculations |
The Electron volt....

- Charge on the electron is $1e = 1.6 \times 10^{-19} \text{ C}$  
  (eq1)

- But we also know from electrical circuits; $1V = 1 \text{ J C}^{-1}$

- So by multiplying equation 1 by $1V$ on each side we get:

  $1e \times 1V = 1V \times 1.6 \times 10^{-19} \text{ C}$ (eq2)

- Then sub in $1\text{J C}^{-1}$ for the voltage part on the RHS of (eq2) gives us;

  $1e \times 1V = 1\text{J C}^{-1} \times 1.6 \times 10^{-19} \text{ C}$

- This leaves us with definition: $1\text{eV} = 1.6 \times 10^{-19} \text{ J}$

  $1\text{MeV} = 1 \times 10^6 \times 1\text{eV}$

We can use this a smaller version of the joule (not a smaller version of the volt!)
Another way of thinking about it is saying that the current carries the energy;

As the Coulombs of Charge move they release their energy as heat and light (through the bulb)
The MeV and E=mc²

- We can now use this definition to make things on a particle level easier to deal with: \(1\text{eV} = 1.6 \times 10^{-19} \text{J}\)

- We can say that \(5\text{MeV}\) can be converted to joules by........

\[
1.6 \times 10^{-19} \text{J} \times 5 \times 10^6 = 8 \times 10^{-13} \text{J}
\]

- This can be taken a step further by saying that since \(E = mc^2\) we can also represent mass as \(E/c^2\).

- If we take mass of a proton \(1u = 1.67 \times 10^{-27} \text{kg}\). Then we can say that the energy of proton (at rest) is found as;

\[
E = mc^2 = 1.67 \times 10^{-27} \text{kg} \times (3.00 \times 10^8 \text{ ms}^{-1})^2 = 1.503 \times 10^{-10} \text{J}
\]

\[
E = 1.503 \times 10^{-10} \text{J} / 1.6 \times 10^{-19} \text{JeV}^{-1} = 939\text{MeV} \text{ or } 0.939\text{GeV}
\]

NB: we should also remember that: \(J = \text{kgm}^2\text{s}^{-2}\)
Beta Decay....

- In this case a neutron converts to a proton, $\beta^-$, anti-$\nu$

- In this case a proton converts to a neutron, $\beta^+$, $\nu$

\[ \begin{array}{c|c|c}
\text{neutron number } N \\
\hline
Z & Z+1 & N-1 \\
\hline
N & & \\
\end{array} \]

\[ \begin{array}{c|c|c}
\text{proton number } Z \\
\hline
Z & Z-1 & N+1 \\
\hline
N & & \\
\end{array} \]
What is Antimatter?

Corresponding to most kinds of particles, there is an associated antiparticle with the same mass and opposite electric charge.

The laws of nature are very nearly symmetrical with respect to particles and antiparticles. For example, an antiproton and a positron can form an antihydrogen atom, which has almost exactly the same properties as a hydrogen atom.

Particle-antiparticle pairs can annihilate each other, producing photons; since the charges of the particle and antiparticle are opposite, charge is conserved. For example, the antielectrons produced in natural radioactive decay quickly annihilate themselves with electrons, producing pairs of gamma rays.

Although particles and their antiparticles have opposite charges, electrically neutral particles need not be identical to their antiparticles. The neutron, for example, is made out of quarks, the antineutron from antiquarks, and they are distinguishable from one another because neutrons and antineutrons annihilate each other upon contact.
Antimatter Summary

- For each particle of matter there is an equivalent antiparticle. A few particles (e.g. photons) are their own antiparticles.

- Antimatter consists of antiparticles. An antiparticle and a particle pair can be produced from a photon of high-energy radiation, which ceases to exist as a result.

- An antiparticle has:

  1. equal but opposite spin to its particle counterpart (not req AS)

  2. equal but opposite charge to its particle counterpart if its particle counterpart is charged;

  3. a mass (rest energy) equal to the mass of its particle counterpart.
Annihilation

In which a particle and a corresponding antiparticle collide and annihilate each other, producing two photons of total momentum and total energy equal to the initial momentum and energy of the particle and antiparticle, including their combined rest energy $2mc^2$.

We can use the proton as an example of this....

If we take mass of a proton $1u = 1.66 \times 10^{-27}$kg.

Then we can say that the energy of the proton (at rest) or antiproton is found as;

$$E = mc^2 = 1.67 \times 10^{-27} \text{kg} \times (3.00 \times 10^8 \text{ ms}^{-1})^2 = 1.503 \times 10^{-10} \text{J}$$

$$E = 1.503 \times 10^{-10} \text{J} / 1.6 \times 10^{-19} \text{ JeV}^{-1} = 939 \text{MeV or 0.939GeV} = 1878 \text{MeV.}$$

This energy will then be split between the two. The energy contained in the two photons must be double this or $2mc^2 = 2 \times 939 \text{MeV}$ photons in opposite directions.

**NB:** properties such as charge, spin, and lepton or baryon number are equal but opposite for particles and their antiparticles.
Electron- Positron Annihilation

Energy is conserved

<table>
<thead>
<tr>
<th>total energy before</th>
<th>=</th>
<th>total energy after</th>
</tr>
</thead>
<tbody>
<tr>
<td>= kinetic energy of particles + rest energy of particles</td>
<td></td>
<td>energy after is energy of gamma photons</td>
</tr>
<tr>
<td>minimum value of energy before is rest energy:</td>
<td></td>
<td>= 2 × 0.511 MeV</td>
</tr>
<tr>
<td>= 2 mc² = 2 × 0.511 MeV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Momentum is conserved

<table>
<thead>
<tr>
<th>total linear momentum before</th>
<th>=</th>
<th>total linear momentum after</th>
</tr>
</thead>
<tbody>
<tr>
<td>e⁻ → e⁺</td>
<td></td>
<td>γ → γ</td>
</tr>
<tr>
<td>same mass; equal and opposite velocities</td>
<td></td>
<td>energy E, momentum p = E/c</td>
</tr>
<tr>
<td>total momentum before = 0</td>
<td></td>
<td>photons identical, momenta opposite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total momentum = 0</td>
</tr>
</tbody>
</table>

Charge is conserved

<table>
<thead>
<tr>
<th>total charge before</th>
<th>=</th>
<th>total charge after</th>
</tr>
</thead>
<tbody>
<tr>
<td>charge</td>
<td></td>
<td>charge</td>
</tr>
<tr>
<td>(−e) + (+e) = 0</td>
<td></td>
<td>0 + 0 = 0</td>
</tr>
</tbody>
</table>

NB: Assume equal collision speeds

Mass proton 1u = 1.66 x 10⁻²⁷ kg.

Mass of electron = (1/1840)u

What is the rest energy in Joules and MeV for an electron?

E = 8.12 x 10⁻¹⁴ J
E = 0.507 MeV
Pair Annihilation & Creation

**Annihilation**

- gamma energy
  - $= 2 \times 0.511 \text{ MeV}$ plus kinetic energy of electrons

- extremely rare (cannot bring two identical photons together)

**Creation**

- gamma energy
  - $= 2 \times 0.511 \text{ MeV}$ (minimum)

- nucleus carries away momentum, to conserve momentum and energy

- close to nucleus
Pair Production

In which a high-energy photon produces a particle and its antiparticle.

This can only occur if the photon energy $E = hf = \frac{hc}{\lambda}$ is greater than or equal to $2mc^2$,

where $m$ is the mass of the particle, with rest energy $mc^2$ for each particle of the pair produced.

More generally, particles are always created in particle–antiparticle pairs. The masses of particles and their antiparticles are identical.

All other properties, such as charge, spin, lepton or baryon number, are equal but opposite in sign.
Pair Production

In which a high-energy photon produces a particle and its antiparticle. This can only occur if the photon energy $hf$ is greater than or equal to $2mc^2$, where $m$ is the mass of the particle produced, with rest energy $mc^2$ for each particle of the pair.

Using the diagram above as an example if we take mass of an electron to be $1u/1840 = 9.11 \times 10^{-31}kg$

Then we can say that the energy to produce an electron (at rest) is found as;

$$E = mc^2 = 9.11 \times 10^{-31}kg \times (3.00 \times 10^8 \text{ ms}^{-1})^2 = 8.199 \times 10^{-14}J$$

$$E = 1.503 \times 10^{-10}J/ 1.6 \times 10^{-19} \text{ JeV}^{-1} = 0.51\text{MeV}$$

The energy contained in the particle and antiparticle must be double this or

$$2mc^2 = 2 \times 0.51\text{MeV} = 1.02\text{MeV}.$$

This energy will then be split between the particles. Hence the gamma ray photon must have at least this energy to produce these particles.
Carl Anderson – Evidence of Positron?

Positron enters and is slowed by lead plate. Then curvature increases.

Beta particle would curve in other direction.

(a) Evidence for the positron

(positron enters here)

lead plate

magnetic field into diagram

positron loses energy in the plate
Bubble Chambers..

The development of bubble chambers in the 1950s allowed particle physicists to ‘see’ particle interactions more easily and more rapidly than earlier work which used cloud chambers or photographic emulsions.

Many bubble chambers consisted of liquid hydrogen which is held at its boiling point. When the pressure is reduced the liquid becomes ‘superheated’ (a strange concept at –253 °C!) and bubbles will form on any ions in the liquid.

The passage of a charged particle through the chamber produces ions in the liquid and the bubbles formed on the ions trace its track.

These chambers were used as the targets for beams of particles – with the interactions triggered when the incoming particles collide with (or pass close to) a hydrogen nucleus (which is simply a proton).

Before they became obsolete with the advent of electronic detectors and massive computing power, bubble chambers provided much of the evidence which led to the **Standard Model** of particle physics.
Figure 2 (b) shows a bubble chamber photograph depicting two electron-positron pairs created in a magnetic field. The gamma photon does not leave a track because it is uncharged. Students might like to consider

- why the tracks curve in opposite directions from the point of production
- the significance of the curvature in terms of particle momentum
- the cause of the spirals
- the minimum photon energy needed to cause pair production of an electron and a positron, given the rest energy of an electron is 0.55 MeV.
Particle Interactions....
Bubble Chamber....

Basically an electron and a positron (an anti-electron) are drawn together due to their opposite charges.

When they inevitably collide their material existence comes to an end and they are turned into gamma ray photons.

Then two gamma ray photons can be converted into an electron-positron pair, bringing forth matter from whence none existed.
Proton–antiproton annihilation

Here an antiproton (coming in from the bottom left) strikes a proton.

Mutual annihilation leads to four pairs of $\pi^+$ and $\pi^-$. These curve in opposite directions in the magnetic field.

To think about:

the antiproton is being deflected slightly to the right. So can you identify the $\pi^+$ and $\pi^-$ particle tracks?

- The magnetic field is directed “into the page” (NB anti-proton has a negative charge). It is a rotation of previous slide.

- The $\pi^+$ and $\pi^-$ particle tracks are red and green respectively (the $\pi^-$ will deflect the same way as the anti-proton)
Another view!
The proton enters from the bottom and strikes a proton in the liquid hydrogen bubble chamber.

The collision produces a spray of negative and positive particles as well as an unseen neutral lambda particle.

The unseen lambda decays into a further pair of positive and negative particles slightly further up from the collision point.

What produces the spiral track shown at the bottom of the picture?
Alpha & Protons

This picture shows the tracks produced by an alpha particle and a proton in a strong magnetic field.

Which track was made by the proton and which by the alpha particle? (Think about the charge to mass ratios of the two particles.)

Alpha - $\frac{+2}{4} = +0.5$
Proton -> +1

Alpha
Proton
Electron
Can you explain this idea?
Question....

Using this picture can you come up with a brief set of rules for behaviours in a bubble chamber.....
# 1.5 How particles interact p13-15

<table>
<thead>
<tr>
<th>K</th>
<th>What is the Electromagnetic Force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What is the weak nuclear force</td>
</tr>
<tr>
<td></td>
<td>What is electron capture</td>
</tr>
</tbody>
</table>

| S | Interpreting Feynman Diagrams    |

<table>
<thead>
<tr>
<th>U</th>
<th>How can you construct a Feynman Diagram to represent interactions and decays for... beta +/- decay, proton-electron collision, electron capture, neutron-neutrino interaction &amp; proton-antineutrino interactions.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What are exchange particles</td>
</tr>
</tbody>
</table>
How do matter particles interact?

There are four fundamental interactions between particles.

When thinking about it the problem is that things interact without touching!

How do two magnets "feel" each other's presence and attract or repel accordingly? How does the sun attract the earth?

We know the answers to these questions are "magnetism" and "gravity," but what are these forces?

At a fundamental level, a force isn't just something that happens to particles. **It is a thing which is passed between two particles.**

Photons are responsible for the electromagnetic one!
Want some proof...

- These two players throw a ball to each other and thus slowly move apart as they absorb the energy.

- If you look that them without the ball in the picture it looks strange!

- We know that the ball carries the force.
Grand Unified Theory Gauge Bosons

- Gravitons
- Photons
- Gluons
- W & Z Bosons
Fundamental Forces - alternate

**Strong**
- Gluons (8)
- Quarks
- Mesons
- Baryons
- Nuclei

**Electromagnetic**
- Photon
- Atoms
- Light
- Chemistry
- Electronics

**Gravitational**
- Graviton?
- Solar system
- Galaxies
- Black holes

**Weak**
- Bosons (W,Z)
- Neutron decay
- Beta radioactivity
- Neutrino interactions
- Burning of the sun
Gauge Bosons in more detail

The Electromagnetic Force - The Electromagnetic force acts between charged particles and is transmitted by the mass-less particle THE PHOTON.

The Strong Interaction – Acts between nucleons (protons and neutrons) and is transmitted by the Gauge Boson called the GLUON. Theory has predicted that there are 8 of them but you don’t need to know this.

The Weak Interaction – Acts over an even shorter range than the strong interaction. It acts on both Leptons and Hadrons and is transmitted by 3 bosons called; W+, W- and Z Bosons.

Gravity – The gauge boson that transmits the gravitational force is the GRAVITON. This has never as of yet been discovered and is predicted to have zero mass.
Fundamental Forces Summary....

**Strong**
- Force which holds nucleus together
- Strength: $1$
- Range (m): $10^{-15}$
  (diameter of a medium sized nucleus)
- Particle: gluons, $\pi$ (nucleons)

**Electromagnetic**
- Strength: $\frac{1}{137}$
- Range (m): Infinite
- Particle: photon
  - mass = 0
  - spin = 1

**Weak**
- Neutrino interaction induces beta decay
- Strength: $10^{-6}$
- Range (m): $10^{-18}$
  (0.1% of the diameter of a proton)
- Particle: intermediate vector bosons $W^+, W^-, Z_0$
  - mass $> 80$ GeV
  - spin = 1

**Gravity**
- Strength: $6 \times 10^{-39}$
- Range (m): Infinite
- Particle: graviton?
  - mass = 0
  - spin = 2
### Comparison of Gauge Bosons...

<table>
<thead>
<tr>
<th>interaction</th>
<th>force carrier</th>
<th>electric charge</th>
<th>rest energy / GeV</th>
<th>explains</th>
</tr>
</thead>
<tbody>
<tr>
<td>electromagnetism</td>
<td>photon</td>
<td>0</td>
<td>0</td>
<td>Everyday interactions including all chemistry</td>
</tr>
<tr>
<td>weak interaction</td>
<td>Z⁰</td>
<td>0</td>
<td>93</td>
<td>Radioactive decays; changing particle nature</td>
</tr>
<tr>
<td></td>
<td>W⁺</td>
<td>+1</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W⁻</td>
<td>−1</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>strong interaction</td>
<td>8 different ‘colour combinations’ of gluons</td>
<td>0</td>
<td>0</td>
<td>What holds nucleons and mesons together</td>
</tr>
<tr>
<td>gravity</td>
<td>‘graviton’</td>
<td>0</td>
<td>0</td>
<td>Conjectured, but not detected</td>
</tr>
</tbody>
</table>

**NB:** Graviton & Z⁰ not required in AS
Feynman Diagrams

- The eminent Physicist Richard Feynman invented a graphical method to represent interactions of particles.

- The only thing that really means anything is the time and direction of the arrows.

- At each vertex there must be equal charge into and out of the point of interaction.

- The angles are not significant.

- In this case a neutron turns into a proton as a quark has a change of flavour.

- The exchange particle is a $W^-$ boson and results in an electron antineutrino and electron.
At each vertex there must be equal charge into and out of the point of interaction.

Consider each vertex on its own.

Each vertex will either cancel, carry through +1 or -1 charge.

When a lepton is released an anti-lepton is required to balance lepton number.

All diagrams relate to a p or n interacting with lepton.
Focus on the W+/W-

- $W^+$ and $W^-$ are each other's particle and antiparticle
- When we think of a decay what we actually mean is...

\[
\begin{align*}
n &\rightarrow p + W^- \\
W^- &\rightarrow e^- + \overline{\nu}_e
\end{align*}
\]

- This helps when thinking about charge being conserved
- The second reaction taking place a very short time and distance after the initial change. 0.001fm
- $W$ particles have a mass and charge.
Each of these diagrams shows the same decay....
Predict & Explain what comes out?

**b** \( \beta^+ \) decay

**a** \( \beta^- \) decay

\( p = \text{proton} \)
\( n = \text{neutron} \)