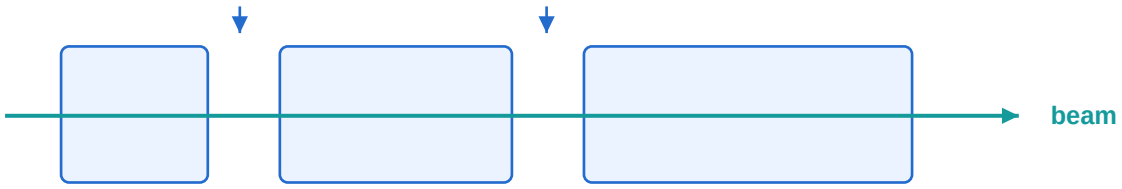
LESSON 4.3.3

Accelerators, Detectors and Particle Classification

Electric fields transfer energy to charged particles. Magnetic fields bend their paths. Detectors then reveal evidence of charge, momentum and particle interactions.

LINEAR ACCELERATOR: REPEATED ACCELERATING GAPS



Gaps accelerate; the ideal tube interiors shield the beam from E.

An alternating voltage reverses while particles are inside the tubes. They reach each gap when its field accelerates them forwards. At non-relativistic speeds, later tubes are longer to match the increasing speed.

$$\Delta K = |q|V$$

V is the magnitude of the accelerating potential difference. Thermionic emission releases electrons from a heated metal cathode; a positive anode accelerates them. Vacuum reduces collisions with gas.

EXAMPLE: ELECTRON ACCELERATED THROUGH 4.00 kV

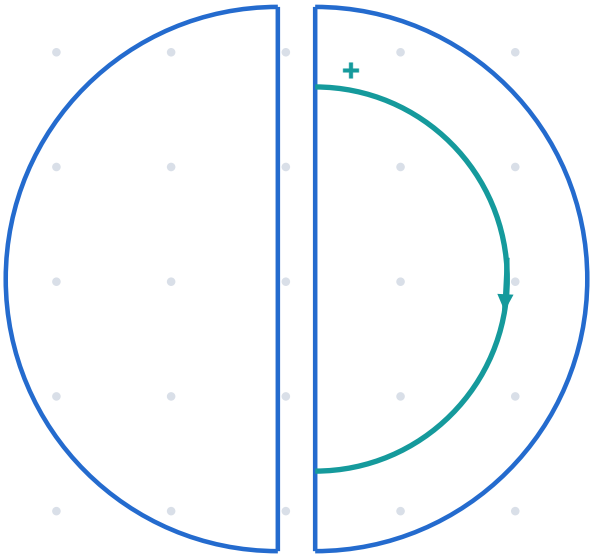
$$\Delta K = (1.60 \times 10^{-19})(4000) = 6.40 \times 10^{-16}\ \text{J}$$

Its kinetic energy increases by 4.00 keV; add any initial kinetic energy separately.

Why high energy? Higher momentum gives a shorter de Broglie wavelength ($\lambda = h/p$), allowing smaller structures to be resolved. Sufficient available collision energy can also create massive particles.

1 Reuse the gap in a cyclotron

A uniform magnetic field bends charged particles inside two hollow D-shaped electrodes, called dees.



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1. ELECTRIC FIELD IN THE GAP

The gap voltage alternates so the field reverses every half-turn. The particle gains kinetic energy each time it crosses.

2. MAGNETIC FIELD INSIDE DEES

The magnetic force changes direction, not speed. One clockwise half-turn of a positive ion is shown; the next crossing gives a larger orbit.

The ideal model assumes a uniform B, motion perpendicular to B, and speeds well below c.

$$r = \frac{mv}{B|q|} \qquad T = \frac{2\pi m}{B|q|} \qquad f = \frac{B|q|}{2\pi m}$$

As speed rises, radius increases. The full-turn period is independent of speed in this non-relativistic model, so a fixed-frequency alternating voltage can stay synchronised.

EXAMPLE: PROTON IN B = 0.500 T

$$f = \frac{(0.500)(1.60 \times 10^{-19})}{2\pi(1.67 \times 10^{-27})} = 7.62 \times 10^{6}\ \text{Hz}$$

The driving frequency is about 7.62 MHz; a half-turn takes half the period.

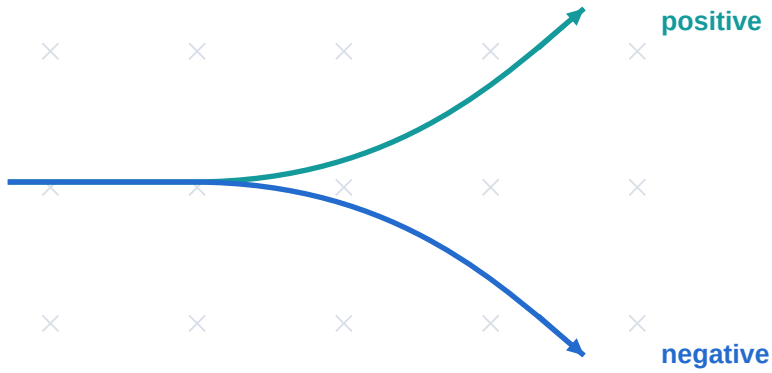
At relativistic speeds, p is no longer mv and the orbit period increases. A simple fixed-frequency cyclotron loses synchronisation; more advanced accelerators compensate.

A magnetic field alone cannot supply the kinetic-energy increase.

2 Read the evidence in a particle track

Charged particles ionise detector material. A cloud chamber or bubble chamber makes their paths visible.

KNOWN MOTION TO THE RIGHT; B INTO THE PAGE



Separate paths, not a decay. Arrows show motion; crosses show B into the page.

$$r = \frac{p}{B|q|} \qquad p = B|q|r$$

Here motion is perpendicular to B; for a helix use perpendicular momentum. For equal charge magnitude in the same field, a larger radius means greater momentum, not necessarily greater speed. The bend alone does not identify a particle.

EXAMPLE: |q| = e, B = 0.500 T, r = 0.120 m

$$p = (0.500)(1.60 \times 10^{-19})(0.120) = 9.60 \times 10^{-21} \text{ kg m/s}$$

If the particle loses momentum by ionisation in uniform B, its radius decreases.

Neutral particles do not leave direct ionisation tracks like charged particles. Infer them from interactions or missing energy and momentum. Track density depends on charge and speed as well as detector conditions.

RELATIVISTIC LIFETIME: WHY FAST MUONS CAN TRAVEL FAR

An unstable particle moving very fast has a longer measured mean lifetime in the laboratory than in its own rest frame. Atmospheric muons can therefore reach the ground in much larger numbers than a non-relativistic estimate predicts.

3 Classify by internal structure

Quarks and leptons are fundamental in the Standard Model. Hadrons are composite particles made of quarks.

BARYONS

Three quarks in the standard examples: proton uud, neutron udd. Antibaryons contain three antiquarks. Baryons and mesons are both hadrons.

MESONS

A quark and an antiquark in the standard examples, such as pions. A meson is not a lepton, even though both have baryon number zero.

QUARK FAMILIES AND ELECTRIC CHARGE

Up-type: up (u), charm (c), top (t)	**+2e/3 each**
Down-type: down (d), strange (s), bottom (b)	**-e/3 each**

Antiquarks have opposite charge. Quark-family symmetry predicted a top partner for the bottom quark before the top quark was discovered.

WORKED CHARGE CHECKS

Proton: uud 2/3 + 2/3 - 1/3 = +1

Positive pion: $u\bar{d}$ 2/3 + 1/3 = +1

These totals are in units of e. A neutral neutron has 2/3 - 1/3 - 1/3 = 0.

LEPTONS AND PHOTONS

Leptons include the electron, muon and tau, and their three associated neutrinos, with corresponding antiparticles. They are not made of quarks. The photon is a fundamental carrier of the electromagnetic interaction; it has zero electric charge and zero rest mass.

A photon still carries energy and momentum: E = hf and p = E/c.

Source: Pearson IAL Physics, Unit 4 p. 31, points 113-117 and 120-121.

Course lesson numbering. Diagrams are schematic, not apparatus construction plans.