

Exercise walk-through

24.3

PET scanning

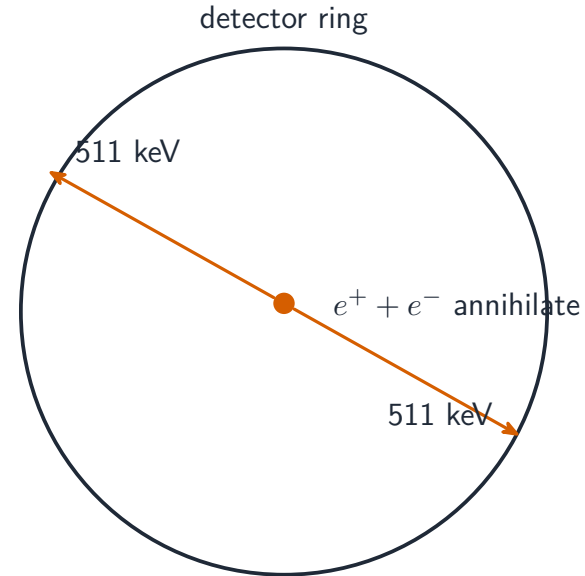
A-Level Physics

A β^+ tracer, then annihilation

A **tracer** (often FDG, fluorine-18 on a glucose analogue) is taken up more by active tissue. In PET it is a β^+ emitter – it gives out a **positron**. The positron

meets an electron and they **annihilate**: two photons, opposite directions, each 511 keV ($= m_e c^2$).

$$2hf = 2m_e c^2$$



two photons, opposite directions — the coincidence fixes the line

PET: annihilation gives two 511 keV photons in opposite directions; a coincidence fixes the line

A coincidence fixes the line

The two photons hit detector rings around the patient. Two simultaneous arrivals (a coincidence) fix the line the annihilation lay on. Many coincidences from many angles build a 3-D map of the tracer – tissues with high metabolic activity.

Comparing arrival times can refine the position along that line (time-of-flight PET).

Tracers and annihilation

a tracer

a substance containing radioactive nuclei, introduced into the body

how it works

it is **taken up more** by the tissue being studied, so that tissue emits more strongly

the choice

a γ or β^+ emitter with a **short half-life**, so the dose falls quickly

an antiparticle

the same mass, opposite charge – the positron is the electron's

annihilation

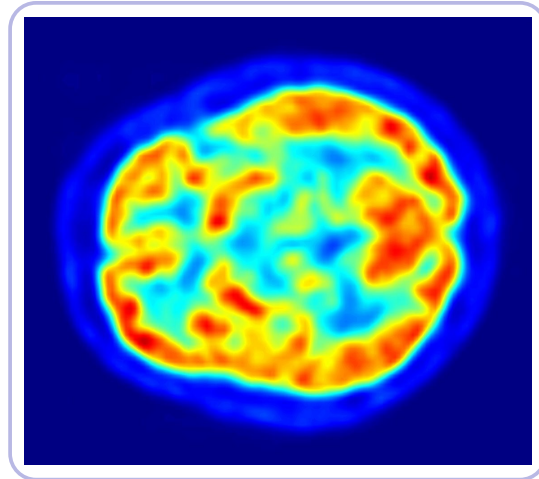
a particle meets its antiparticle and their **mass turns into electromagnetic energy**

the signature

two γ photons of 0.51 MeV leave in **opposite directions**, and detecting both fixes the line the event lay on

PET works because momentum conservation forces the two photons back to back. That geometry is what locates the tracer.

A finished PET image



Positron emission tomography

(PET) maps function, not shape: warm colours mark where the tracer collected – the tissue with the fastest metabolism.

Exam tips

- **Ultrasound** reflects at boundaries (acoustic impedance); a coupling gel reduces reflection at the skin.
- **X-rays** are attenuated as $I = I_0 e^{-\mu x}$; contrast media (barium, iodine) absorb strongly.
- **PET** uses a positron emitter; annihilation gives two γ -rays in opposite directions, located by the detector ring.

Exercises 2.1-2.3

2.1 State what a **tracer** is.

[1]

2.2 State the type of **decay** a PET tracer undergoes.

[1]

2.3 Explain what **annihilation** is.

[2]

Exercises 2.1-2.3

2.1 State what a **tracer** is.

[1]

2.1

- a substance containing **radioactive nuclei** introduced into the body and **taken up** by the tissue being studied

2.2 State the type of **decay** a PET tracer undergoes.

[1]

2.2

- β^+ (**positron**) decay

2.3 Explain what **annihilation** is.

[2]

2.3

- when a particle meets its **antiparticle**, they are destroyed
- and their **mass becomes energy** (electromagnetic radiation)

Exercises 2.4·3.1

2.4 State the **energy** of each annihilation photon.

[1]

3.1 In PET, the two γ photons from an annihilation travel:

[1]

☐

A in the same direction

B in opposite directions

C at right angles

D in random directions

Exercises 2.4·3.1

2.4 State the **energy** of each annihilation photon. [1]

2.4

- 511 keV ($= m_e c^2$)

3.1 In PET, the two γ photons from an annihilation travel: [1]

☐

A in the same direction

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C at right angles

D in random directions

3.1 B

- the two photons travel **in opposite directions**

Exercises 3.2-3.3

3.2 Calculate the **energy** of each γ photon produced when an electron and positron annihilate. ($m_e = 9.11 \times 10^{-31}$ kg.) [3]

3.3 Explain why **two** photons are produced (not one), travelling in opposite directions.[2]

Exercises 3.2-3.3

3.2 Calculate the **energy** of each γ photon produced when an electron and positron annihilate. ($m_e = 9.11 \times 10^{-31}$ kg.) [3]

3.2

- total rest energy $= 2m_e c^2$, shared by two photons, so each $E = m_e c^2$

$$E = m_e c^2 = (9.11 \times 10^{-31} \text{ kg})(3.0 \times 10^8 \frac{\text{m}}{\text{s}})^2 = \mathbf{8.2 \times 10^{-14} \text{ J}}$$

(= 511 keV)

3.3 Explain why **two** photons are produced (not one), travelling in opposite directions.[2]

3.3

- momentum must be **conserved**
- the pair's total momentum is ≈ 0 , so the photons must go in **opposite directions** with equal momentum (a single photon could not conserve momentum)

Exercise 3.4

3.4 Explain how detecting the two photons helps locate the **annihilation** event. [2]

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3.4

- both photons are detected (almost simultaneously) on **opposite sides** of the ring
- the annihilation lies on the **straight line** joining the two detectors – combining many such lines builds the image