

AQA A-Level Physics: Particle Physics – Calculation Questions

Praneel Physics

1. Calculate the energy of a photon with wavelength 400 nm. (P)

Working and Answer:

Use $E = \frac{hc}{\lambda}$.

$h = 6.63 \times 10^{-34} \text{ Js}$, $c = 3.00 \times 10^8 \text{ m/s}$, $\lambda = 400 \times 10^{-9} \text{ m}$.

Calculate $E = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{400 \times 10^{-9}} = 4.97 \times 10^{-19} \text{ J}$.

2. Calculate the momentum of an electron accelerated through a potential difference of 500 V. (P)

Working and Answer:

Electron charge $e = 1.6 \times 10^{-19}$ C, potential difference $V = 500$ V.

Kinetic energy $KE = eV = 1.6 \times 10^{-19} \times 500 = 8.0 \times 10^{-17}$ J.

Momentum $p = \sqrt{2mKE}$, with $m = 9.11 \times 10^{-31}$ kg.

Calculate $p = \sqrt{2 \times 9.11 \times 10^{-31} \times 8.0 \times 10^{-17}} = 1.21 \times 10^{-23}$ kg m/s.

3. Calculate the de Broglie wavelength of a proton moving at 2.0×10^6 m/s. (P)

Working and Answer:

Mass of proton $m = 1.67 \times 10^{-27}$ kg.

Momentum $p = mv = 1.67 \times 10^{-27} \times 2.0 \times 10^6 = 3.34 \times 10^{-21}$ kg m/s.

De Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{3.34 \times 10^{-21}} = 1.99 \times 10^{-13}$ m.

4. Calculate the frequency of a photon with energy 3.3×10^{-19} J. (P)

Working and Answer:

Use $E = hf$.

$h = 6.63 \times 10^{-34}$ Js, so $f = \frac{E}{h} = \frac{3.3 \times 10^{-19}}{6.63 \times 10^{-34}} = 4.98 \times 10^{14}$ Hz.

5. Calculate the energy of a photon emitted when an electron falls from $n = 3$ to $n = 2$ in hydrogen. Given $E_3 = -1.51 \text{ eV}$, $E_2 = -3.40 \text{ eV}$. (P)

Working and Answer:

Energy released $E = E_2 - E_3 = -3.40 - (-1.51) = 1.89 \text{ eV}$.

Convert to joules: $E = 1.89 \times 1.60 \times 10^{-19} = 3.02 \times 10^{-19} \text{ J}$.

6. Calculate the momentum of a photon with wavelength 600 nm. (P)

Working and Answer:

Momentum $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{600 \times 10^{-9}} = 1.11 \times 10^{-27} \text{ kg m/s}$.

7. Calculate the kinetic energy of an electron with momentum $3.0 \times 10^{-24} \text{ kg m/s}$. (**PP**)

Working and Answer:

Given $p = 3.0 \times 10^{-24} \text{ kg m/s}$ and electron mass $m = 9.11 \times 10^{-31} \text{ kg}$.

Use $KE = \frac{p^2}{2m}$.

Calculate $KE = \frac{(3.0 \times 10^{-24})^2}{2 \times 9.11 \times 10^{-31}} = \frac{9.0 \times 10^{-48}}{1.82 \times 10^{-30}} = 4.95 \times 10^{-18} \text{ J}$.

8. Calculate the wavelength of an electron accelerated through $1.0 \times 10^3 \text{ V}$. (PP)

Working and Answer:

Electron charge $e = 1.6 \times 10^{-19} \text{ C}$, voltage $V = 1.0 \times 10^3 \text{ V}$.

Kinetic energy $KE = eV = 1.6 \times 10^{-19} \times 1.0 \times 10^3 = 1.6 \times 10^{-16} \text{ J}$.

Momentum

$p = \sqrt{2mKE} = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-16}} = 5.39 \times 10^{-23} \text{ kg m/s}$.

De Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{5.39 \times 10^{-23}} = 3.88 \times 10^{-11} \text{ m}$.

9. Calculate the rest energy of a neutron. (PP)

Working and Answer:

Mass of neutron $m = 1.675 \times 10^{-27} \text{ kg}$.

Use $E = mc^2$, where $c = 3.00 \times 10^8 \text{ m/s}$.

Calculate $E = 1.675 \times 10^{-27} \times (3.00 \times 10^8)^2 = 1.51 \times 10^{-10} \text{ J}$.

10. Calculate the frequency of a photon with energy 3.3×10^{-19} J. (P)

Working and Answer:

Use $E = hf$.

$$h = 6.63 \times 10^{-34} \text{ Js, so } f = \frac{E}{h} = \frac{3.3 \times 10^{-19}}{6.63 \times 10^{-34}} = 4.98 \times 10^{14} \text{ Hz.}$$

11. Calculate the energy of a photon emitted when an electron falls from $n = 3$ to $n = 2$ in hydrogen. Given $E_3 = -1.51$ eV, $E_2 = -3.40$ eV. (P)

Working and Answer:

Energy released $E = E_2 - E_3 = -3.40 - (-1.51) = 1.89$ eV.

Convert to joules: $E = 1.89 \times 1.60 \times 10^{-19} = 3.02 \times 10^{-19}$ J.

12. Calculate the momentum of a photon with wavelength 600 nm. (P)

Working and Answer:

$$\text{Momentum } p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{600 \times 10^{-9}} = 1.11 \times 10^{-27} \text{ kg m/s.}$$

13. Calculate the kinetic energy of a proton accelerated through a potential difference of 2.0×10^6 V and find its velocity. **(PPP)**

Working and Answer:

Step 1: Calculate kinetic energy

$$KE = eV = 1.6 \times 10^{-19} \times 2.0 \times 10^6 = 3.2 \times 10^{-13} \text{ J.}$$

Step 2: Use $KE = \frac{1}{2}mv^2$ with $m = 1.67 \times 10^{-27}$ kg to find v .

$$\text{Rearranged: } v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-13}}{1.67 \times 10^{-27}}} = 1.96 \times 10^7 \text{ m/s.}$$

Step 3: Calculate relativistic correction by finding $\gamma = \frac{1}{\sqrt{1-(v/c)^2}} \approx 1.006$ (negligible).

14. Calculate the momentum and de Broglie wavelength of an electron with kinetic energy 1.0×10^{-17} J. (PPP)

Working and Answer:

Step 1: Calculate momentum

$$p = \sqrt{2mKE} = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.0 \times 10^{-17}} = 4.27 \times 10^{-24} \text{ kg m/s.}$$

Step 2: Calculate de Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{4.27 \times 10^{-24}} = 1.55 \times 10^{-10} \text{ m.}$

Step 3: Comment on wavelength being in X-ray region.

15. Calculate the energy released when a proton and an antiproton annihilate each other. (PPP)

Working and Answer:

Step 1: Rest mass of proton $m = 1.67 \times 10^{-27}$ kg.

Step 2: Total mass annihilated $2m = 3.34 \times 10^{-27}$ kg.

Step 3: Energy $E = (2m)c^2 = 3.34 \times 10^{-27} \times (3.00 \times 10^8)^2 = 3.01 \times 10^{-10}$ J.

16. Calculate the frequency of a photon with energy 3.3×10^{-19} J. (P)

Working and Answer:

Use $E = hf$.

$h = 6.63 \times 10^{-34}$ Js, so $f = \frac{E}{h} = \frac{3.3 \times 10^{-19}}{6.63 \times 10^{-34}} = 4.98 \times 10^{14}$ Hz.

17. Calculate the energy of a photon emitted when an electron falls from $n = 3$ to $n = 2$ in hydrogen. Given $E_3 = -1.51 \text{ eV}$, $E_2 = -3.40 \text{ eV}$. (P)

Working and Answer:

Energy released $E = E_2 - E_3 = -3.40 - (-1.51) = 1.89 \text{ eV}$.

Convert to joules: $E = 1.89 \times 1.60 \times 10^{-19} = 3.02 \times 10^{-19} \text{ J}$.

18. Calculate the momentum of a photon with wavelength 600 nm. (P)

Working and Answer:

Momentum $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{600 \times 10^{-9}} = 1.11 \times 10^{-27} \text{ kg m/s}$.

19. Calculate the speed of a relativistic electron with kinetic energy 1.6×10^{-14} J. (PPPP)

Working and Answer:

Step 1: Calculate total energy

$$E = KE + mc^2 = 1.6 \times 10^{-14} + 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 1.6 \times 10^{-14} + 8.2 \times 10^{-14} = 9.8 \times 10^{-14} \text{ J.}$$

Step 2: Calculate relativistic momentum $p = \sqrt{\frac{E^2}{c^2} - m^2c^2}$. Substitute values to find p .

Step 3: Calculate velocity $v = \frac{pc^2}{E}$.

Step 4: Numerical evaluation gives $v \approx 2.8 \times 10^8$ m/s (about $0.93c$).

20. Calculate the kinetic energy of a pion produced in a collision if its momentum is $4.0 \times 10^{-20} \text{ kg m/s}$ and its rest mass is $2.49 \times 10^{-28} \text{ kg}$. (PPPP)

Working and Answer:

Step 1: Calculate total energy $E = \sqrt{(pc)^2 + (mc^2)^2}$.

Calculate $pc = 4.0 \times 10^{-20} \times 3.00 \times 10^8 = 1.2 \times 10^{-11} \text{ J}$.

Calculate $mc^2 = 2.49 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.24 \times 10^{-11} \text{ J}$.

Step 2: Compute $E = \sqrt{(1.2 \times 10^{-11})^2 + (2.24 \times 10^{-11})^2} = 2.52 \times 10^{-11} \text{ J}$.

Step 3: Kinetic energy

$KE = E - mc^2 = 2.52 \times 10^{-11} - 2.24 \times 10^{-11} = 2.8 \times 10^{-12} \text{ J}$.

Step 4: Final answer: $KE = 2.8 \times 10^{-12} \text{ J}$.

21. Calculate the de Broglie wavelength of an alpha particle ($m = 6.64 \times 10^{-27}$ kg) with kinetic energy 5.0×10^{-13} J. (PPPP)

Working and Answer:

Step 1: Calculate momentum

$$p = \sqrt{2mKE} = \sqrt{2 \times 6.64 \times 10^{-27} \times 5.0 \times 10^{-13}} = 8.16 \times 10^{-20} \text{ kg m/s.}$$

Step 2: Calculate wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{8.16 \times 10^{-20}} = 8.12 \times 10^{-15} \text{ m.}$

Step 3: Discuss relation to nuclear scale.

22. Calculate the speed of an electron given it has a relativistic momentum of 3.0×10^{-22} kg m/s.
(PPPP)

Working and Answer:

Step 1: Electron rest mass $m = 9.11 \times 10^{-31}$ kg, speed of light
 $c = 3.00 \times 10^8$ m/s.

Step 2: Calculate

$$\gamma = \sqrt{1 + \left(\frac{p}{mc}\right)^2} = \sqrt{1 + \left(\frac{3.0 \times 10^{-22}}{9.11 \times 10^{-31} \times 3.00 \times 10^8}\right)^2} = \sqrt{1 + (109.7)^2} \approx 109.7.$$

Step 3: Calculate $v = c \sqrt{1 - \frac{1}{\gamma^2}} = 3.00 \times 10^8 \sqrt{1 - \frac{1}{109.7^2}} = 2.9999 \times 10^8$ m/s.

23. Calculate the relativistic kinetic energy of an electron moving at 2.7×10^8 m/s. (PPPP)

Working and Answer:

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(2.7 \times 10^8 / 3.00 \times 10^8)^2}} = 2.25.$$

Rest energy $E_0 = 8.2 \times 10^{-14}$ J.

$$\text{Kinetic energy } KE = (\gamma - 1)E_0 = (2.25 - 1) \times 8.2 \times 10^{-14} = 1.02 \times 10^{-13} \text{ J.}$$

24. Calculate the total energy of a proton moving at 2.4×10^8 m/s. (PPPP)

Working and Answer:

$$\gamma = \frac{1}{\sqrt{1-(2.4 \times 10^8 / 3.00 \times 10^8)^2}} = 1.54.$$

Rest energy $E_0 = 1.5 \times 10^{-10}$ J.

$$\text{Total energy } E = \gamma E_0 = 1.54 \times 1.5 \times 10^{-10} = 2.31 \times 10^{-10} \text{ J.}$$

25. Calculate the velocity of a particle with rest mass 9.1×10^{-31} kg and momentum 2.5×10^{-22} kg m/s. (PPPP)

Working and Answer:

$$\text{Calculate } \gamma = \sqrt{1 + \left(\frac{p}{mc}\right)^2} = \sqrt{1 + \left(\frac{2.5 \times 10^{-22}}{9.1 \times 10^{-31} \times 3.00 \times 10^8}\right)^2} = \sqrt{1 + (91.3)^2} = 91.3.$$

$$\text{Velocity } v = c \sqrt{1 - \frac{1}{\gamma^2}} = 3.00 \times 10^8 \times \sqrt{1 - \frac{1}{(91.3)^2}} = 2.9998 \times 10^8 \text{ m/s.}$$

26. Calculate the relativistic kinetic energy of an electron moving at 2.7×10^8 m/s. (PPPP)

Working and Answer:

$$\gamma = \frac{1}{\sqrt{1 - (v/c)^2}} = \frac{1}{\sqrt{1 - (2.7 \times 10^8 / 3.00 \times 10^8)^2}} = 2.25.$$

$$\text{Rest energy } E_0 = 8.2 \times 10^{-14} \text{ J.}$$

$$\text{Kinetic energy } KE = (\gamma - 1)E_0 = (2.25 - 1) \times 8.2 \times 10^{-14} = 1.02 \times 10^{-13} \text{ J.}$$

27. Calculate the total energy of a proton moving at 2.4×10^8 m/s. (PPPP)

Working and Answer:

$$\gamma = \frac{1}{\sqrt{1 - (2.4 \times 10^8 / 3.00 \times 10^8)^2}} = 1.54.$$

$$\text{Rest energy } E_0 = 1.5 \times 10^{-10} \text{ J.}$$

$$\text{Total energy } E = \gamma E_0 = 1.54 \times 1.5 \times 10^{-10} = 2.31 \times 10^{-10} \text{ J.}$$

28. Calculate the velocity of a particle with rest mass 9.1×10^{-31} kg and momentum 2.5×10^{-22} kg m/s. (PPPP)

Working and Answer:

$$\text{Calculate } \gamma = \sqrt{1 + \left(\frac{p}{mc}\right)^2} = \sqrt{1 + \left(\frac{2.5 \times 10^{-22}}{9.1 \times 10^{-31} \times 3.00 \times 10^8}\right)^2} = \sqrt{1 + (91.3)^2} = 91.3.$$

$$\text{Velocity } v = c \sqrt{1 - \frac{1}{\gamma^2}} = 3.00 \times 10^8 \times \sqrt{1 - \frac{1}{(91.3)^2}} = 2.9998 \times 10^8 \text{ m/s.}$$

29. Calculate the kinetic energy and velocity of an electron given its total energy is twice its rest energy. (PPPPP)

Working and Answer:

Step 1: Electron rest energy

$$E_0 = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.2 \times 10^{-14} \text{ J.}$$

Step 2: Total energy $E = 2E_0 = 1.64 \times 10^{-13} \text{ J.}$

Step 3: Kinetic energy $KE = E - E_0 = 8.2 \times 10^{-14} \text{ J.}$

Step 4: Calculate Lorentz factor $\gamma = \frac{E}{E_0} = 2.$

Step 5: Calculate velocity

$$v = c\sqrt{1 - \frac{1}{\gamma^2}} = 3.00 \times 10^8 \times \sqrt{1 - \frac{1}{4}} = 2.60 \times 10^8 \text{ m/s.}$$

30. Calculate the momentum and de Broglie wavelength of a muon with rest mass 1.88×10^{-28} kg moving at 2.0×10^7 m/s. (PPPPP)

Working and Answer:

Step 1: Calculate relativistic momentum $p = \gamma mv$, where $\gamma = \frac{1}{\sqrt{1-(v/c)^2}}$.

Calculate $v/c = \frac{2.0 \times 10^7}{3.00 \times 10^8} = 0.067$, so $\gamma = \frac{1}{\sqrt{1-0.067^2}} = 1.002$.

Calculate $p = 1.002 \times 1.88 \times 10^{-28} \times 2.0 \times 10^7 = 3.77 \times 10^{-21}$ kg m/s.

Step 2: Calculate de Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{3.77 \times 10^{-21}} = 1.76 \times 10^{-13}$ m.

31. Calculate the total energy and kinetic energy of a particle with rest mass 2.0×10^{-27} kg moving at 2.5×10^8 m/s. (PPPPP)

Working and Answer:

Step 1: Calculate

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(2.5 \times 10^8 / 3.00 \times 10^8)^2}} = \frac{1}{\sqrt{1-0.6944}} = \frac{1}{0.552} = 1.81.$$

Step 2: Calculate total energy

$$E = \gamma mc^2 = 1.81 \times 2.0 \times 10^{-27} \times (3.00 \times 10^8)^2 = 3.26 \times 10^{-10} \text{ J}.$$

Step 3: Calculate rest energy

$$E_0 = mc^2 = 2.0 \times 10^{-27} \times (3.00 \times 10^8)^2 = 1.8 \times 10^{-10} \text{ J}.$$

Step 4: Calculate kinetic energy

$$KE = E - E_0 = 3.26 \times 10^{-10} - 1.8 \times 10^{-10} = 1.46 \times 10^{-10} \text{ J}.$$