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 $E = \frac{hc}{\lambda}$.
$h = 6.63 \times 10^{-34}$ Js, $c = 3.00 \times 10^{8}$ m/s, $\lambda = 400 \times 10^{-9}$ m.
Calculate $E = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{400 \times 10^{-9}} = 4.97 \times 10^{-19}$ 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 $2.0 \times 10^6\,\text{m/s}$. **(P)**

Working and Answer:
Mass of proton $m = 1.67 \times 10^{-27}\,\text{kg}$.
Momentum $p = mv = 1.67 \times 10^{-27} \times 2.0 \times 10^6 = 3.34 \times 10^{-21}\,\text{kg m/s}$.
De Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{3.34 \times 10^{-21}} = 1.99 \times 10^{-13}\,\text{m}$.

4. Calculate the frequency of a photon with energy $3.3 \times 10^{-19}\,\text{J}$. **(P)**

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

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 $KE = \frac{(3.0\times10^{-24})^2}{2\times9.11\times10^{-31}} = \frac{9.0\times10^{-48}}{1.82\times10^{-30}} = 4.95 \times 10^{-18}\,\text{J}$.

8. Calculate the wavelength of an electron accelerated through 1.0×10^3 V. **(PP)**

Working and Answer:
Electron charge $e = 1.6 \times 10^{-19}$ C, voltage $V = 1.0 \times 10^3$ V.
Kinetic energy $KE = eV = 1.6 \times 10^{-19} \times 1.0 \times 10^3 = 1.6 \times 10^{-16}$ J.
Momentum
$p = \sqrt{2mKE} = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-16}} = 5.4 \times 10^{-23}$ kg m/s.
De Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{5.4 \times 10^{-23}} = 1.23 \times 10^{-11}$ m.

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

Working and Answer:
Mass of neutron $m = 1.675 \times 10^{-27}$ kg.
Use $E = mc^2$, where $c = 3.00 \times 10^8$ m/s.
Calculate $E = 1.675 \times 10^{-27} \times (3.00 \times 10^8)^2 = 1.51 \times 10^{-10}$ J.

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

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

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

Working and Answer:
Energy released $E = E_2 - E_3 = -3.40 - (-1.51) = -1.89\,\text{eV}$.
Convert to joules: $E = 1.89 \times 1.60 \times 10^{-19} = 3.02 \times 10^{-19}$ J.

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

Working and Answer:
Momentum $p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{600\times10^{-9}} = 1.11 \times 10^{-27}\,\text{kg m/s}$.

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
$KE = eV = 1.6 \times 10^{-19} \times 2.0 \times 10^6 = 3.2 \times 10^{-13}$ J.
Step 2: Use $KE = \frac{1}{2}mv^2$ with $m = 1.67 \times 10^{-27}$ kg to find v.
Rearranged: $v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-13}}{1.67 \times 10^{-27}}} = 1.96 \times 10^7$ 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
$p = \sqrt{2mKE} = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.0 \times 10^{-17}} = 1.35 \times 10^{-23}\,\text{kg m/s}$.
Step 2: Calculate de Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{1.35 \times 10^{-23}} = 4.91 \times 10^{-11}\,\text{m}$.
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
$E = KE + mc^2 = 1.6 \times 10^{-14} + 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 =$
$1.6 \times 10^{-14} + 8.2 \times 10^{-14} = 9.8 \times 10^{-14}$ 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 ($m = 6.64 \times 10^{-27}\,\text{kg}$) with kinetic energy $5.0 \times 10^{-13}\,\text{J}$. **(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 $3.0\times10^{-22}\,\text{kg m/s}$. **(PPPP)**

Working and Answer:
Step 1: Electron rest mass $m = 9.11 \times 10^{-31}\,\text{kg}$, speed of light $c = 3.00 \times 10^{8}\,\text{m/s}$.
Step 2: Calculate
$\gamma = \sqrt{1 + \left(\frac{p}{mc}\right)^2} = \sqrt{1 + \left(\frac{3.0\times10^{-22}}{9.11\times10^{-31}\times3.00\times10^{8}}\right)^2} = \sqrt{1 + (109.7)^2} \approx 109.7.$
Step 3: Calculate $v = c\sqrt{1 - \frac{1}{\gamma^2}} = 3.00 \times 10^{8}\sqrt{1 - \frac{1}{109.7^2}} = 2.9999 \times 10^{8}\,\text{m/s}.$

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

Working and Answer:
$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(2.7\times10^8/3.00\times10^8)^2}} = 2.25.$
Rest energy $E_0 = 8.2 \times 10^{-14}$ J.
Kinetic energy $KE = (\gamma - 1)E_0 = (2.25 - 1) \times 8.2 \times 10^{-14} = 1.02 \times 10^{-13}$ J.

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

Working and Answer:
$\gamma = \frac{1}{\sqrt{1-(2.4\times10^8/3.00\times10^8)^2}} = 1.54.$
Rest energy $E_0 = 1.5 \times 10^{-10}$ J.
Total energy $E = \gamma E_0 = 1.54 \times 1.5 \times 10^{-10} = 2.31 \times 10^{-10}$ J.

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

Working and Answer:
Calculate $\gamma = \sqrt{1 + \left(\frac{p}{mc}\right)^2} = \sqrt{1 + \left(\frac{2.5\times10^{-22}}{9.1\times10^{-31}\times3.00\times10^{8}}\right)^2} = \sqrt{1 + (91.3)^2} = 91.3.$
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 $2.7 \times 10^8\,\text{m/s}$. **(PPPP)**

Working and Answer:
$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(2.7\times10^8/3.00\times10^8)^2}} = 2.25.$
Rest energy $E_0 = 8.2 \times 10^{-14}\,\text{J}.$
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:
$\gamma = \frac{1}{\sqrt{1-(2.4\times10^8/3.00\times10^8)^2}} = 1.54.$
Rest energy $E_0 = 1.5 \times 10^{-10}$ J.
Total energy $E = \gamma E_0 = 1.54 \times 1.5 \times 10^{-10} = 2.31 \times 10^{-10}$ 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:
Calculate $\gamma = \sqrt{1+\left(\frac{p}{mc}\right)^2} = \sqrt{1+\left(\frac{2.5\times10^{-22}}{9.1\times10^{-31}\times3.00\times10^8}\right)^2} = \sqrt{1+(91.3)^2} = 91.3.$
Velocity $v = c\sqrt{1-\frac{1}{\gamma^2}} = 3.00 \times 10^8 \times \sqrt{1-\frac{1}{(91.3)^2}} = 2.9998 \times 10^8$ 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
$E_0 = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.2 \times 10^{-14}$ J.
Step 2: Total energy $E = 2E_0 = 1.64 \times 10^{-13}$ J.
Step 3: Kinetic energy $KE = E - E_0 = 8.2 \times 10^{-14}$ J.
Step 4: Calculate Lorentz factor $\gamma = \frac{E}{E_0} = 2$.
Step 5: Calculate velocity
$v = c\sqrt{1 - \frac{1}{\gamma^2}} = 3.00 \times 10^8 \times \sqrt{1 - \frac{1}{4}} = 2.60 \times 10^8$ m/s.

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

Working and Answer:
Step 1: Calculate relativistic momentum $p = \gamma m v$, where $\gamma = \frac{1}{\sqrt{1-(v/c)^2}}$.
Calculate $v/c = \frac{2.0\times10^{7}}{3.00\times10^{8}} = 0.067$, so $\gamma = \frac{1}{\sqrt{1-0.067^2}} = 1.002$.
Calculate $p = 1.002 \times 1.88 \times 10^{-28} \times 2.0 \times 10^{7} = 3.77 \times 10^{-21}\,\text{kg m/s}$.
Step 2: Calculate de Broglie wavelength $\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{3.77\times10^{-21}} = 1.76 \times 10^{-13}\,\text{m}$.

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
$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(2.5\times10^8/3.00\times10^8)^2}} = \frac{1}{\sqrt{1-0.6944}} = \frac{1}{0.552} = 1.81.$
Step 2: Calculate total energy
$E = \gamma mc^2 = 1.81 \times 2.0 \times 10^{-27} \times (3.00 \times 10^8)^2 = 3.26 \times 10^{-10}$ J.
Step 3: Calculate rest energy
$E_0 = mc^2 = 2.0 \times 10^{-27} \times (3.00 \times 10^8)^2 = 1.8 \times 10^{-10}$ J.
Step 4: Calculate kinetic energy
$KE = E - E_0 = 3.26 \times 10^{-10} - 1.8 \times 10^{-10} = 1.46 \times 10^{-10}$ J.