Edexcel A2 Physics: Nuclear and Particle Physics – Calculation Practice

Praneel Physics

1. Calculate the mass of a neutron in kilograms, given that its mass is approximately 1.675×10^{-27} kg. **(P)**

Working and Answer:
Mass of neutron = 1.675×10^{-27} kg.

2. If a proton has a charge of $+1.6 \times 10^{-19}$ C, what is the total charge of 3 protons? **(P)**

Working and Answer:
Total charge $= 3 \times 1.6 \times 10^{-19}$ C $= 4.8 \times 10^{-19}$ C.

3. A radioactive isotope has a half-life of 5 years. If you start with 80 grams, how much will remain after 15 years? **(P)**

Working and Answer:
After 15 years (3 half-lives) : $\frac{80}{2^3} = \frac{80}{8} = 10$ grams.

4. Calculate the energy released when 1 kg of mass is converted to energy using $E = mc^2$. (Use $c = 3 \times 10^8$ m/s) **(P)**

Working and Answer:
$E = mc^2 = 1 \times (3 \times 10^8)^2 = 9 \times 10^{16}$ J.

5. What is the binding energy of a helium-4 nucleus, given that its mass defect is 0.0304 u? (Use 1 u = 931.5 MeV/c^2) **(P)**

Working and Answer:
Binding energy = 0.0304×931.5 MeV = 28.34 MeV.

6. A carbon-14 nucleus decays to nitrogen-14 by beta decay. If the decay constant λ is 1.21×10^{-4} year^{-1}, calculate the half-life of carbon-14. **(PP)**

Working and Answer:
$T_{1/2} = \dfrac{\ln(2)}{\lambda} = \dfrac{0.693}{1.21 \times 10^{-4}} \approx 5730$ years.

7. Calculate the total energy of a photon emitted during a transition from the n=3 to n=2 energy level in a hydrogen atom. (Use Rydberg constant $R_H = 1.097 \times 10^7$ m^{-1}) **(PP)**

Working and Answer:
$E = h \cdot f = h \cdot R_H \cdot \left(\dfrac{1}{2^2} - \dfrac{1}{3^2}\right) = 6.626 \times 10^{-34} \cdot 1.097 \times 10^7 \cdot \left(\dfrac{1}{4} - \dfrac{1}{9}\right) \approx 1.89 \times 10^{-19}$ J.

8. If a sample contains 1000 radioactive atoms and has a decay constant of 0.693 year^{-1}, how many atoms will remain after 1 year? **(PP)**

Working and Answer:
$N = N_0 e^{-\lambda t} = 1000 e^{-0.693 \cdot 1} \approx 500$ atoms.

9. A particle has a rest mass of 0.511 MeV/c^2. Calculate its total energy when it is moving at 0.8c. **(PP)**

Working and Answer:
$E = \gamma mc^2, \gamma = \dfrac{1}{\sqrt{1-(0.8)^2}} \approx 1.667, E \approx 1.667 \times 0.511 \text{ MeV} \approx 0.853 \text{ MeV}.$

10. Calculate the radius of a nucleus with a mass number of 56 using the empirical formula $R = R_0 A^{1/3}$ where $R_0 = 1.2$ fm. **(PP)**

Working and Answer:
$R = 1.2 \times 56^{1/3} \approx 1.2 \times 3.83 \approx 4.6$ fm.

11. A neutron star has a mass of 2.0×10^{30} kg and a radius of 10 km. Calculate its average density. **(PPP)**

Working and Answer:
$$\text{Density} = \frac{mass}{volume} = \frac{2.0 \times 10^{30}}{\frac{4}{3}\pi(10^3)^3} \approx 5.0 \times 10^{17} \text{ kg/m}^3.$$

12. If the energy of a gamma photon is 1.25 MeV, calculate its wavelength. (Use $E = \frac{hc}{\lambda}$) **(PPP)**

Working and Answer:
$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34})(3 \times 10^{8})}{1.25 \times 1.6 \times 10^{-13}} \approx 1.58 \times 10^{-12}$ m.

13. A particle has a kinetic energy of 10 MeV. Calculate its relativistic momentum. **(PPP)**

Working and Answer:
$K.E. = \gamma mc^2 - mc^2 \Rightarrow \gamma = \frac{K.E. + mc^2}{mc^2}, p = \gamma mv.$ (Use $m = 0.511$ MeV/c^2)

14. Calculate the number of alpha particles emitted by a radioactive source with a decay rate of 200 decays per minute over 10 minutes. **(PPP)**

Working and Answer:
$N =$ decay rate $\times$ time $= 200 \times 10 = 2000$ alpha particles.

15. A positron has a mass of 9.11×10^{-31} kg. Calculate its energy at rest. **(PPP)**

Working and Answer:
$E = mc^2 = (9.11 \times 10^{-31})(3 \times 10^8)^2 \approx 8.19 \times 10^{-14}$ J.

16. If a certain isotope has a decay constant of 0.1 day^{-1}, how long will it take for 75% of the sample to decay? **(PPPP)**

Working and Answer:
$T = \dfrac{\ln(0.25)}{-\lambda} = \dfrac{\ln(0.25)}{-0.1} \approx 27.7$ days.

17. Calculate the energy released in the fusion of deuterium and tritium to form helium-4 and a neutron, given that the mass defect is 0.0187 u. **(PPPP)**

Working and Answer:
$E = \Delta mc^2 = 0.0187 \times 931.5 \approx 17.4$ MeV.

18. A particle travels at 0.9c. Calculate its relativistic mass compared to its rest mass. **(PPPP)**

Working and Answer:
$\gamma = \dfrac{1}{\sqrt{1-(0.9)^2}} \approx 2.294$, Relativistic mass $= \gamma m_0$.

19. If the radius of a nucleus is 7 fm, calculate its volume. **(PPPP)**

Working and Answer:
$V = \dfrac{4}{3}\pi R^3 = \dfrac{4}{3}\pi(7 \times 10^{-15})^3 \approx 1.54 \times 10^{-43}$ m^3.

20. A radioactive isotope has a half-life of 10 years. If you start with 160 grams, how much will remain after 30 years? **(PPPP)**

Working and Answer:
$N = N_0 \left(\frac{1}{2}\right)^{t/T_{1/2}} = 160 \left(\frac{1}{2}\right)^{3} = 20$ grams.

21. Calculate the total energy of a system of 3 protons and 2 neutrons in MeV, given that the mass of a proton is 0.938 MeV/c^2 and a neutron is 0.939 MeV/c^2. **(PPPPP)**

Working and Answer:
$E = (3 \times 0.938 + 2 \times 0.939)$ MeV $= 5.692$ MeV.

22. A particle has a total energy of 5 MeV and a rest mass of 0.5 MeV/c². Calculate its speed. **(PPPPP)**

Working and Answer:
$E = \gamma mc^2 \Rightarrow \gamma = \dfrac{E}{mc^2}, v = c\sqrt{1 - \dfrac{1}{\gamma^2}}.$

23. Calculate the energy required to remove a neutron from a nucleus with a binding energy of 8 MeV. **(PPPPP)**

Working and Answer:
$E = 8$ MeV (energy required to remove the neutron).

24. If a particle has a momentum of 1.0×10^{-22} kg m/s and a rest mass of 0.511 MeV/c^2, calculate its total energy. **(PPPPP)**

Working and Answer:
$E^2 = (pc)^2 + (m_0c^2)^2, E = \sqrt{(1.0 \times 10^{-22} \cdot 3 \times 10^8)^2 + (0.511 \cdot 1.6 \times 10^{-13})^2}$.

25. A nucleus undergoes alpha decay, emitting an alpha particle with a kinetic energy of 5 MeV. Calculate the recoil energy of the daughter nucleus. **(PPPPP)**

Working and Answer:
$E_{\text{recoil}} = \dfrac{(m_{\text{alpha}})^2}{(m_{\text{alpha}} + m_{\text{daughter}})} \cdot KE_{\text{alpha}}$.