Pearson Physics Level 30
Unit VIII Atomic Physics: Unit VIII Review Solutions

Student Book pages 855–859

Vocabulary

1. **absorption line spectrum:** a pattern of dark lines produced when light passes through a gas at low pressure
   activity (*A*) or decay rate: the number of nuclei in a sample that decay within a given time
   alpha radiation: the emission of a helium nucleus
   antimatter: a form of matter that has a key property, such as charge, opposite to that of ordinary matter
   atomic mass number (*A*): the number of nucleons in the nucleus, $Z + N$
   atomic mass unit (u): exactly $\frac{1}{12}$ the mass of a carbon-12 atom: $1.660\ 539 \times 10^{-27}$ kg
   atomic number (*Z*): the total number of protons in an atomic nucleus
   baryon: a hadron with half-integer spin
   becquerel (Bq): unit of activity, equal to 1 decay per second
   beta (β) particle: an electron emitted by a nucleus
   beta radiation: the emission of a high-energy electron
   beta-negative (β^-) decay: nuclear decay involving emission of an electron
   beta-positive (β^+) decay: nuclear decay involving emission of a positron
   binding energy: the net energy required to liberate all of the protons and neutrons in a nucleus
   Bohr radius: the radius of the smallest orbit in a hydrogen atom
   boson: particle with integer spin
   bubble chamber: a device that uses trails of bubbles in a superheated liquid to show the paths of charged particles
   cathode ray: free electrons emitted by a negative electrode
   cloud chamber: a device that uses trails of droplets of condensed vapour to show the paths of charged particles
   colour: a quantum property related to the strong nuclear force
   cyclotron: particle accelerator in which a magnetic field perpendicular to the paths of the charged particles makes them follow circular paths within two hollow semicircular electrodes
   daughter element: the element produced by a decay process
   decay constant: probability of a nucleus decaying in a given time
   drift tube accelerator: particle accelerator in which an alternating voltage accelerates charged particles through a series of electrodes shaped like open tubes
   electroweak force: a fundamental force that combines the electromagnetic force and the weak nuclear force
   elementary unit of charge: the charge on a proton

emission line spectrum: a pattern of bright lines produced by a hot gas at low pressure
energy level: a discrete and quantized amount of energy
excited state: any energy level higher than the ground state
femto: prefix meaning 10^{-15}
fermion: particle with half-integer spin
fission: reaction in which a nucleus with $A > 120$ splits into smaller nuclei that have greater binding energy per nucleon; the energy given off equals the difference between the binding energy of the original nucleus and the total binding energy of the products
Fraunhofer line: a dark line in the spectrum of the Sun
fundamental particle: a particle that cannot be divided into smaller particles; an elementary particle
fusion: reaction in which two low-mass nuclei combine to form a single nucleus with $A < 60$, resulting in a nucleus that is more tightly bound; the energy given off equals the difference between the total binding energy of the original nuclei and the binding energy of the product
gamma (γ) decay: emission of a high-energy photon by a nucleus
gamma radiation: the emission of a high-energy photon
gluon: the mediating particle for the strong nuclear force
grand unified theory: quantum theory unifying the electromagnetic, strong nuclear, and weak nuclear forces
graviton: the hypothetical mediating particle for the gravitational force
gray (Gy): dose of ionizing radiation that delivers 1 J of energy to each kilogram of material absorbing the radiation
ground state: the lowest possible energy level
hadron: a subatomic particle that interacts via the strong nuclear force
half-life: the time it takes for half of the radioactive nuclei in a sample to decay
ionization energy: the energy required to remove an electron from an atom
isotopes: atoms that have the same number of protons, but different numbers of neutrons
lepton: a subatomic particle that does not interact via the strong nuclear force
mass defect: the difference between the sum of the masses of the individual nucleons forming a nucleus and the actual mass of that nucleus
mediating particle: a virtual particle that carries one of the fundamental forces
meson: a hadron with integer spin
muon: an unstable subatomic particle having many of the properties of an electron but a mass 207 times greater
neutrino: an extremely small neutral subatomic particle
neutron: a neutral particle found in nuclei
neutron number (N): the total number of neutrons in an atomic nucleus.
nucleon: a proton or neutron
nucleosynthesis: formation of elements by the fusion of lighter elements
orbital: a probability distribution for an electron
parent element: the original element in a decay process
pion: an unstable subatomic particle with a mass roughly 270 times that of an electron
planetary model: an atomic model that has electrons orbiting the nucleus

positron (e^+ or ${}^{0}_{1}\beta$): an antielectron; a positively charged particle with its other properties the same as those of an electron
primary cosmic rays: high-energy particles that flow from space into Earth's atmosphere
principal quantum number: the quantum number that determines the size and energy of an orbit
proton: a positively charged particle found in all nuclei
proton-proton chain: fusion process in which four hydrogen nuclei combine to form a helium nucleus
quantum chromodynamics: quantum field theory that describes the strong nuclear force in terms of quantum colour
quantum electrodynamics: quantum field theory dealing with the interactions of electromagnetic fields, charged particles, and photons
quantum field theory: a field theory developed using both quantum mechanics and relativity theory
quark: any of the group of fundamental particles in hadrons
radioactive decay series: a process of successive nuclear decays
radioisotope: an isotope that is radioactive
relative biological effectiveness (RBE): a factor indicating how much a particular type of radiation affects the human body
secondary cosmic rays: the shower of particles created by collisions between primary cosmic rays and atoms in the atmosphere
sievert (Sv): absorbed dose of ionizing radiation that has the same effect on a person as 1 Gy of photon radiation, such as X rays or gamma rays
spectrometer: a device for measuring the wavelengths of light in a spectrum
spectroscopy: the study of light emitted and absorbed by different materials
spin: quantum property resembling rotational angular momentum
standard model: the current theory describing the nature of matter and the fundamental forces
stationary state: a stable state with a fixed energy level
strange particle: a particle that interacts primarily via the strong nuclear force yet decays only via the weak nuclear force
string theory: theory that treats particles as quantized vibrations of extremely small strings of mass-energy
strong nuclear force: the force that binds together the protons and neutrons in a nucleus
supernova: sudden, extremely powerful explosion of a massive star
synchrotron: an advanced type of cyclotron particle accelerator that increases the strength of the magnetic field as the particles' energy increases, so that the particles travel in a circle rather than spiralling outward
transmute: change into a different element
Van de Graaff accelerator: particle accelerator in which a moving belt transfers charge to a hollow, conductive sphere, building up a large potential difference that propels ions through an accelerator chamber
virtual particle: a particle that exists for such a short time that it is not detectable
weak nuclear force: a fundamental force that acts on electrons and neutrinos

Knowledge

Chapter 15

2. ***Given***

m = 1 kg of protons

Required

charge of 1 kg of protons (Q)

Analysis and Solution

One proton has a charge of 1.60×10^{-19} C and a mass of 1.67×10^{-27} kg.

$$\text{number of protons} = \frac{\text{mass}}{\text{mass per proton}} = N$$

Q = charge = number of protons × charge

$$\begin{aligned} Q &= N(1.60 \times 10^{-19}\,\text{C}) \\ &= \left(\frac{1\,\text{kg}}{1.67 \times 10^{-27}\,\text{kg}}\right)(1.60 \times 10^{-19}\,\text{C}) \\ &= 9.6 \times 10^{7}\,\text{C} \end{aligned}$$

Paraphrase

A 1-kg mass of protons would have an enormous charge of 96 000 000 C!

3. ***Given***

$n = 10\text{e}^-$

Required

charge (Q)

Analysis and Solution

$Q = nq = n$e, where n is the number of electrons and q is the charge on an electron, -1.60×10^{-19} C.

$$\begin{aligned} Q &= nq \\ &= 10(-1.60 \times 10^{-19}\ \text{C}) \\ &= -1.60 \times 10^{-18}\ \text{C} \end{aligned}$$

Paraphrase

The dust grain has a charge of -1.60×10^{-18} C.

4. ***Given***

$Q = -10$e

$\vec{E} = 100$ N/C [S]

Required

force on the dust grain ($\vec{F}$)

Analysis and Solution

Use the equation $\vec{F} = \vec{E}q$, where the charge on a single electron is 1.60×10^{-19} C.

$$\begin{aligned} \vec{F} &= (100\ \text{N/C})(-10)(1.60 \times 10^{-19}\,\text{C}) \\ &= -1.60 \times 10^{-16}\ \text{N} \end{aligned}$$

The negative sign indicates that the force is in the opposite direction to that of the electric field, so $\vec{F}$ = 1.60×10^{-16} N [N].

Paraphrase

The force on the dust grain is 1.60×10^{-16} N [N].

5. The particle's direction becomes the same as the direction of the electric field. Therefore, the force is in the same direction as the electric field. Thus, the particle must have a positive charge.

6. The magnetic field is out of the page toward you. Use either the right- or left-hand rule. Using the left-hand rule, your thumb points to the right, your fingers point outward from the page, and your palm faces up, indicating the direction of the force on a negative charge. Since the particle deflects the other way, it must be positively charged.

7. An alpha particle is a helium nucleus, which consists of two protons and two neutrons.

8. **(a)** The atom loses energy for the transitions $n_{\mathrm{i}} = 4 \to n_{\mathrm{f}} = 1$ and $n_{\mathrm{i}} = 6 \to n_{\mathrm{f}} = 2$.

(b) The atom gains the most energy for the transition $n_{\mathrm{i}} = 1 \to n_{\mathrm{f}} = 5$.

(c) The transition that emits the shortest wavelength photon is $n_{\mathrm{i}} = 6 \to n_{\mathrm{f}} = 2$.

9. Transition B is more energetic because it emits a shorter-wavelength or higher-frequency photon, according to the equation $E = hf$. The effect that transition A is brighter may indicate that it is a more probable transition.

Chapter 16

10. The general formula for an atom is ${}^{A}_{Z}\mathrm{X}$, where A is the atomic number, which equals the proton number plus the neutron number. In ${}^{64}_{31}\mathrm{Ga}$, A = 64 and Z = 31, the proton number. So, the neutron number is $N = A - Z = 64 - 31 = 33$.

11. The mass of an atom is always less than $Zm_{{}^{1}_{1}\mathrm{H}} + Nm_{\mathrm{neutron}}$ because some of the mass—the mass defect—becomes the binding energy of the atom.

12. Use either the equation $E = mc^2$ or the conversion factor 1 u = 931.5 MeV. Using the conversion factor, 0.021 u × 931.5 MeV/u = 19.6 MeV = 1.96 × 10^7 eV.

13. $7.0 \text{ u} \times \dfrac{1.49 \times 10^{-10} \text{ J}}{1 \text{ u}} = 1.043 \times 10^{-9} \text{ J} = 1.0 \times 10^{-9} \text{ J}$

14. Use the relation $\dfrac{E_{\mathrm{b}}}{c^2} = \Delta m$ or

$$
\begin{aligned}
E_{\mathrm{b}} &= 0.0072 \text{ u} \times \frac{931.5 \text{ MeV}}{1 \text{ u}} \\
&= 6.7 \text{ MeV}
\end{aligned}
$$

15. The activity is the total number of decays per second. It is equal to the number of nuclei × decay rate = (1.5 × 10^{22} nuclei)(1.5 × 10^{-13} decays/s)
= 2.3 × 10^9 decays/s

16. Use the decay pattern ${}^{A}_{Z}\mathrm{X} \to {}^{A}_{Z-1}\mathrm{Y} + {}^{0}_{1}\beta + \nu$.

${}^{18}_{9}\mathrm{F} \to {}^{18}_{8}\mathrm{Y} + {}^{0}_{1}\beta + \nu$

From the periodic table, the daughter nucleus is oxygen-18.

17. ***Given***

sulfur-35

$t_{1/2}$ = 87.51 days

t = one year = 365.25 days

m_0 = 25 g

Required

mass remaining (m)

Analysis and Solution

Substitute the given values into the equation $N = N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$.

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{365.25}{87.51}}$$
$$= \left(\frac{1}{2}\right)^{4.174}$$
$$= 0.055$$

If the mass of the of the original sample is 25 g, then the mass remaining after one year is 25 g × 0.055 = 1.4 g

Paraphrase

The amount of sulfur-35 remaining after a year is 1.4 g.

18. Use the decay pattern ${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\alpha$.

$${}^{228}_{90}\mathrm{Th} \rightarrow {}^{224}_{88}\mathrm{Y} + {}^{4}_{2}\alpha$$

From the periodic table, the daughter nucleus is radium-224.

19. Fission is the splitting apart of a nucleus into two smaller nuclei. Fusion is the joining together of smaller nuclei into a larger nucleus.

Chapter 17

20. A positron is an antielectron. It is a particle of antimatter that has the mass and spin of the electron but the opposite charge.

21. A pion is a subatomic particle that consists of a quark and an antiquark. Pions mediate the strong nuclear force, which holds atomic nuclei together.

22. (a) Use the laws of conservation of mass and energy. Since both the positron and electron have the same mass, calculate the energy released using the equation $E = mc^2$. The mass is two electron masses, or 2 × 0.000 548 63 u, and 1 u is equivalent to 931.5 MeV. The energy released is:

$$E = 2 \times 0.000\ 548\ 63\ \mathrm{u} \times 931.5\ \mathrm{MeV/u}$$
$$= 1.02\ \mathrm{MeV}$$

(b) In order to conserve momentum, the two gamma-ray photons must have equal and opposite momenta. Not only do they travel in opposite directions, but they must also have exactly the same magnitude of momentum and hence the same wavelength.

(c) From part (a), the total energy released by the collision of the positron and the electron is 1.02 MeV, so each gamma ray has an energy of one-half this value, or 0.51 MeV. Since $E = \frac{hc}{\lambda}$,

$$\lambda = \frac{hc}{E}$$
$$= \frac{\left(6.63 \times 10^{-34}\ \cancel{\mathrm{J}} \cdot \cancel{\mathrm{s}}\right)\left(3.00 \times 10^{8}\ \frac{\mathrm{m}}{\cancel{\mathrm{s}}}\right)}{\left(0.51\ \cancel{\mathrm{MeV}}\right)\left(1.602 \times 10^{-13}\ \frac{\cancel{\mathrm{J}}}{\cancel{\mathrm{MeV}}}\right)}$$
$$= 2.4 \times 10^{-12}\ \mathrm{m}$$

23. According to the standard model, quarks are the fundamental constituents of particles. Quarks attract each other via the exchange of gluons, which are the mediating particles for the strong nuclear force.

24. The reaction $\bar{\nu}_e + p \rightarrow n + e^+$ states that a proton (p) combines with an antielectron-neutrino ($\bar{\nu}_e$) to produce a neutron (n) and an antielectron or positron (e^+).

25. **(a)** proton (p)

(b) kaon (K^+)

(c) pion (π^+)

(d) sigma-minus (Σ^-)

26. udd $\rightarrow$ uud + [W^-]

$\rightarrow e^- + \bar{\nu}_e$

Applications

27. **(a)** ***Given***

$q = p^+$

$|\vec{E}| = 400$ N/C

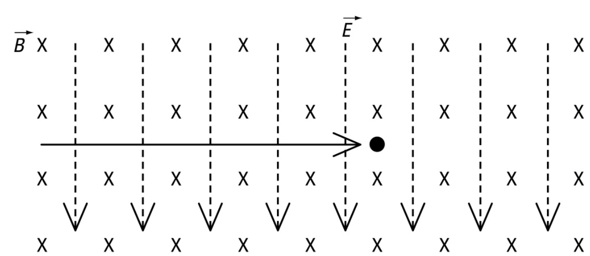
$B = 0.550$ T

Required

orientation of electric and magnetic fields

Analysis and Solution

Use the right-hand rule. Point your thumb in the direction of the protons. If the magnetic field is into the page, then point your fingers into the page. Your palm, and thus the magnetic force, will point upward. The electric field must point downward to provide a downward force.



Paraphrase

The magnetic field is into the page and the electric field points downward.

(b) ***Given***

$q = p^+$

$|\vec{E}| = 400$ N/C

$B = 0.550$ T

Required

speed of the protons (v)

Analysis and Solution

To solve for the speed of the protons, equate the magnitudes of the electric and magnetic forces:

$$F_e = qE$$
$$F_m = Bqv$$
$$\cancel{q}E = B\cancel{q}v$$
$$v = \frac{E}{B} = \frac{400 \text{ N/C}}{0.550 \text{ T}} = 727 \text{ m/s}$$

Paraphrase

To remain undeflected by the electric and magnetic fields, the proton beam must be travelling at 727 m/s.

28. ***Given***

$v = 1.0 \times 10^6$ m/s

$r = 0.50$ m

Required

magnitude of the magnetic field (B)

Analysis and Solution

Use the equation $F_m = qBv = \frac{mv^2}{r}$ and solve for $B = \frac{mv}{qr}$.

Also, $q = +1\ e = 1.60 \times 10^{-19}$ C and m = mass of sodium = 23.0 u = 3.8×10^{-26} kg.

$$B = \frac{(3.8 \times 10^{-26} \text{ kg})(1.0 \times 10^6 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(0.50 \text{ m})} = 0.48 \text{ T}$$

Paraphrase

A magnetic field of strength 0.48 T will deflect the sodium ion.

29. (a) ***Given***

$v_e = 2.5 \times 10^6$ m/s

$\vec{B}$ = 0.50 T [out of the page]

$\vec{E}$ = 100 N/C [down]

Required

magnetic force ($\vec{F}_m$)

electric force ($\vec{F}_e$)

Analysis and Solution

Using the left-hand rule, the magnetic force on the electron is directed upward. The direction of the electric force is also upward. Use the equations $F_m = qBv$ and $F_e = Eq$ to calculate the magnitude of each force.

$$F_m = (1.60 \times 10^{-19} \text{ C})(0.50 \text{ T})(2.5 \times 10^6 \text{ m/s}) = 2.0 \times 10^{-13} \text{ N}$$
$$F_e = (100 \text{ N/C})(1.60 \times 10^{-19} \text{ C}) = 1.60 \times 10^{-17} \text{ N}$$

Paraphrase

The magnetic force is 2.0×10^{-13} N [up] and the electric force is 1.60×10^{-17} N [up].

(b) ***Given***

$v_e = 2.5 \times 10^6$ m/s

$\vec{B}$ = 0.50 T [out of the page]

$\vec{E}$ = 100 N/C [down]

Required

the net force on the particle ($\vec{F}_{net}$)

Analysis and Solution

The net force on the particle is the sum of the electric and magnetic forces.

$$\begin{aligned}\vec{F}_{net} &= \vec{F}_m + \vec{F}_e \\ &= 2.0 \times 10^{-13}\text{ N [up]} + 1.60 \times 10^{-17}\text{ N [up]} \\ &= 2.0 \times 10^{-13}\text{ N [up]}\end{aligned}$$

Paraphrase

The dominant force is the magnetic force, so the electron experiences a net upward force of magnitude 2.0×10^{-13} N.

30. (a) ***Given***

$m = 1.6 \times 10^{-16}$ kg

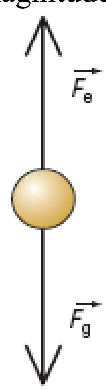
$\vec{E}$ = 981 N/C [down]

Required

net charge on the droplet (q)

Analysis and Solution

The droplet is motionless. This implies that the electric force on the droplet must be upward, so it must have a net negative charge. The charge is stationary, so the magnitude of the electric force must equal the weight of the charge:



$$\begin{aligned}F_e &= F_g \\ Eq &= mg \\ q &= \frac{mg}{E}\end{aligned}$$

$$\begin{aligned}q &= \frac{(1.6 \times 10^{-16}\text{ kg})(9.81\text{ m/s}^2)}{981\text{ N/C}} \\ &= -1.6 \times 10^{-18}\text{ C}\end{aligned}$$

Paraphrase

The net charge on the oil droplet is -1.6×10^{-18} C.

(b) ***Given***

$m = 1.6 \times 10^{-16}$ kg

$\vec{E} = 981$ N/C [down]

Required

number of electrons gained or lost (n)

Analysis and Solution

To find the number of electrons gained or lost, divide the net charge on the oil droplet by the charge per electron, $-1.60 \times 10^{-19}\,\text{C}$.

$$n = \frac{-1.6 \times 10^{-18}\ \text{C}}{-1.6 \times 10^{-19}\ \text{C}}$$
$$= 10$$

Paraphrase

The oil droplet must have gained 10 electrons.

31. (a) Use the equation $\frac{1}{\lambda} = R_{\text{H}}\left(\frac{1}{n^2_{\text{final}}} - \frac{1}{n^2_{\text{initial}}}\right)$, where $R_{\text{H}} = 1.097 \times 10^7\ \text{m}^{-1}$ and $n_{\text{final}} = 3$.

For $n_{\text{i}} = 7 \rightarrow n_{\text{f}} = 3$,

$$\frac{1}{\lambda} = R_{\text{H}}\left(\frac{1}{3^2} - \frac{1}{7^2}\right)$$

$$\frac{1}{\lambda} = (1.097 \times 10^7)(0.09070)$$

$$\lambda = 1005\ \text{nm}$$

For $n_{\text{i}} = 6 \rightarrow n_{\text{f}} = 3$,

$$\frac{1}{\lambda} = R_{\text{H}}\left(\frac{1}{3^2} - \frac{1}{6^2}\right)$$

$$\frac{1}{\lambda} = (1.097 \times 10^7)(0.08333)$$

$$\lambda = 1094\ \text{nm}$$

For $n_{\text{i}} = 5 \rightarrow n_{\text{f}} = 3$,

$$\frac{1}{\lambda} = R_{\text{H}}\left(\frac{1}{3^2} - \frac{1}{5^2}\right)$$

$$\frac{1}{\lambda} = (1.097 \times 10^7)(0.07111)$$

$$\lambda = 1282\ \text{nm}$$

For $n_{\text{i}} = 4 \rightarrow n_{\text{f}} = 3$,

$$\frac{1}{\lambda} = R_{\text{H}}\left(\frac{1}{3^2} - \frac{1}{4^2}\right)$$

$$\frac{1}{\lambda} = (1.097 \times 10^7)(0.04861)$$

$$\lambda = 1875\ \text{nm}$$

(b) These lines are in the infrared part of the spectrum.

32. (a) ***Given***

$n = 2$

Required

radius (r)

Analysis and Solution

According to the Bohr model of the hydrogen atom, $r_n = r_1 n^2$ where $r_1 = 5.29 \times 10^{-11}$ m.

$$r_2 = (5.29 \times 10^{-11}\text{ m})(2)^2$$
$$= 2.12 \times 10^{-10}\text{ m}$$

Paraphrase

The radius of the $n = 2$ energy level of the hydrogen atom is $2.12 \times 10^{-10}\text{ m}$.

(b) ***Given***

$n = 2$

Required

de Broglie wavelength (λ)

Analysis and Solution

Use the equation $2\pi r_n = n\lambda$, where $n = 2$, and the equation $r_n = r_1 n^2$, where $r_1 = 5.29 \times 10^{-11}$ m.

$$\lambda = \frac{2\pi r_n}{n}$$
$$= \frac{2\pi r_1 n^2}{n}$$
$$= 2\pi r_1 n$$

$$\lambda = 2\pi(5.29 \times 10^{-11}\text{ m})(2)$$
$$= 6.65 \times 10^{-10}\text{ m}$$

Paraphrase

The $n = 2$ state electron has a wavelength $\lambda = 6.65 \times 10^{-10}$ m.

(c) ***Given***

$n = 2$

Required

momentum (p)

Analysis and Solution

The formula for de Broglie wavelength is $\lambda = \dfrac{h}{mv}$. Since momentum is $p = mv$, the equation for the momentum of the electron is $p = mv = \dfrac{h}{\lambda}$.

$$p = \frac{6.63 \times 10^{-34}\text{ J}\cdot\text{s}}{6.65 \times 10^{-10}\text{ m}}$$
$$= 9.97 \times 10^{-25}\text{ kg}\cdot\text{m/s}$$

Paraphrase

The momentum of the electron is $9.97 \times 10^{-25}\text{ kg}\cdot\text{m/s}$.

(d) ***Given***

$n = 2$

Required

speed (v)

kinetic energy (E_k)

Analysis and Solution

To find speed, use the equation $p = mv$ and the value for momentum from part (c).

To find kinetic energy, use the equation $E_\text{k} = \frac{p^2}{2m}$. Recall that the mass of an electron is 9.11×10^{-31} kg.

$$\begin{aligned} v &= \frac{p}{m} \\ &= \frac{9.97 \times 10^{-25}\ \cancel{\text{kg}} \cdot \text{m/s}}{9.11 \times 10^{-31}\ \cancel{\text{kg}}} \\ &= 1.09 \times 10^{6}\ \text{m/s} \end{aligned}$$

$$\begin{aligned} E_\text{k} &= \frac{\left(9.97 \times 10^{-25}\ \text{kg} \cdot \text{m/s}\right)^2}{2\left(9.11 \times 10^{-31}\ \text{kg}\right)} \\ &= 5.46 \times 10^{-19}\ \text{J} \end{aligned}$$

Paraphrase

The electron's speed is 1.09×10^{6} m/s and its kinetic energy is 5.46×10^{-19} J.

33. ***Given***

${}^{40}_{20}\text{Ca}$

Required

binding energy (E_b)

Analysis and Solution

Determine the mass defect for the nucleus by using the expression

$$\begin{aligned} \Delta m &= m_\text{nucleons} - m_\text{nucleus} \\ &= Zm_{{}^1_1\text{H}} + Nm_\text{neutron} - m_\text{atom} \end{aligned}$$

Use atomic mass units in all calculations of mass.

From ${}^{40}_{20}\text{Ca}$, $A = 20$ and $N = 40 - 20 = 20$.

$$\begin{aligned} \Delta m &= 20(1.007\ 825\ \text{u}) + 20(1.008\ 665\ \text{u}) - 39.962\ 591\ \text{u} \\ &= 0.367\ 209\ \text{u} \end{aligned}$$

Use the conversion factor 1 u = 931.5 MeV.

$$\begin{aligned} E_\text{b} &= 0.367\ 209\ \text{u} \times 931.5\ \text{MeV/u} \\ &= 342.06\ \text{MeV} \end{aligned}$$

Paraphrase

Calcium has a binding energy of 342.06 MeV.

34. (a) ${}^{12}_{6}\text{C} + \gamma \rightarrow ? + \alpha$

$${}^{12}_{6}\text{C} + \gamma \rightarrow {}^{12-4}_{6-2}\text{X} + {}^{4}_{2}\alpha$$

$${}^{12}_{6}\text{C} + \gamma \rightarrow {}^{8}_{4}\text{Be} + {}^{4}_{2}\alpha$$

The nucleus produced in this reaction is beryllium.

(b) ${}^{14}_{7}\text{N} + \alpha \rightarrow ? + \text{n}$

Absorbing an alpha particle would increase the atomic mass and number.
To conserve charge, the new nucleus must have a total charge of 7 + 2 = 9.
The daughter nucleus must, therefore, be fluorine. Also, the atomic number must increase by 3 units from 14 to 17. So, the daughter nucleus is ${}^{17}_{9}\text{F}$.

(c) ${}^{206}_{81}\text{Tl} \rightarrow ? + \beta^- + \bar{\nu}$

β^- decay will increase the atomic number by one unit but will not change the atomic mass number. The reaction will yield ${}^{206}_{81}\text{Tl} \rightarrow {}^{206}_{82}\text{Pb} + \beta^- + \bar{\nu}$.

The daughter nucleus is lead.

35. (a) ${}^{15}_{6}\text{C} \rightarrow {}^{15}_{5}\text{B} + \beta^+ + \bar{\nu}_e$

This reaction cannot occur because β^+ decay emits a neutrino, not an antineutrino.

(b) ${}^{3}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + \beta^+ + \nu_e$

This reaction cannot occur because β^+ decay always decreases the charge on the nucleus. In this case, charge is not conserved because the decay products have two extra positive charges.

(c) ${}^{23}_{11}\text{Na} + \text{n} \rightarrow {}^{19}_{9}\text{F} + \alpha$

This reaction cannot occur because mass is not conserved in this decay. Absorbing a neutron should change the atomic mass by +1 unit. The total mass on the left-hand side of the equation is 24, but only 23 on the right-hand side.

36. ***Given***

${}^{16}_{7}\text{N}$

β^- decay

Required

energy released (ΔE)

Analysis and Solution

First determine the decay products and then calculate the mass defect for the reaction.

For β^- decay, ${}^{A}_{Z}\text{X} \rightarrow {}^{A}_{Z+1}\text{Y} + {}^{0}_{-1}\beta + \bar{\nu}$. Thus, ${}^{16}_{7}\text{N} \rightarrow {}^{16}_{8}\text{O} + {}^{0}_{-1}\beta + \bar{\nu}$

This reaction produces oxygen.

The mass defect is given by

$$\begin{aligned}
\Delta m &= m_{\text{parent}} - m_{\text{products}} \\
&= m_{{}^{16}_{7}\text{N}} - \left(m_{{}^{16}_{8}\text{O}^+} + m_{{}^{0}_{-1}\beta} \right) \\
&= m_{{}^{16}_{7}\text{N}} - m_{{}^{16}_{8}\text{O}} \\
&= 16.006\ 102\ \text{u} - 15.994\ 915\,\text{u} \\
&= 0.011\ 187\ \text{u}
\end{aligned}$$

The mass defect is 0.011 187 u, so the energy equivalent released is
0.011 187 u × 931.5 MeV/u = 10.42 MeV

Paraphrase

When a radioactive nitrogen nucleus transforms to oxygen via β^- decay, 10.42 MeV of energy is released.

37. ***Given***

$t_{1/2}$ = 8.04 days

t = 30 days

Required

percentage of iodine remaining after 30 days $\left(\dfrac{N}{N_0} \right)$

Analysis and Solution

Use the decay law equation:

$$N = N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

$$\begin{aligned}\frac{N}{N_0} &= \left(\frac{1}{2}\right)^{\frac{30}{8.04}}\\ &= 0.075\end{aligned}$$

$0.075 \times 100\% = 7.5\%$

Paraphrase

After 30 days, 7.5% of iodine-131 will be left.

Note: You are assuming that all of the iodine-131 remains in the body. In fact, most of the iodine will be passed in the patient's urine.

38. ***Given***

${}^{144}_{60}\text{Nd}$

α -decay

Required

energy released (ΔE)

daughter element

Analysis and Solution

Use the alpha decay form ${}^{A}_{Z}\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + {}^{4}_{2}\alpha$ to determine the daughter nucleus.

${}^{144}_{60}\text{Nd} \rightarrow {}^{140}_{58}\text{Ce} + {}^{4}_{2}\alpha$, so cesium-140 is the daughter element.

Use the equation

$$\begin{aligned}\Delta m &= m_{\text{nucleons}} - m_{\text{nucleus}}\\ &= Zm_{{}^{1}_{1}\text{H}} + Nm_{\text{neutron}} - m_{\text{atom}}\end{aligned}$$

to determine the mass defect for these nuclei.

$$\begin{aligned}\Delta m &= 143.910\ 087\ \text{u} - 139.905\ 439\ \text{u} - 4.002\ 603\ \text{u}\\ &= 0.002\ 045\ \text{u}\end{aligned}$$

Use the mass defect to calculate the energy released by the decay process.

$$\begin{aligned}\Delta E &= 0.002\ 045\ \text{u} \times 931.5\ \frac{\text{MeV}}{\text{u}}\\ &= 1.91\ \text{MeV}\end{aligned}$$

Paraphrase

The alpha decay of neodymium releases 1.91 MeV of energy per decay and the daughter element is cesium-140.

39. ***Given***

A = 0.50 MBq

$t_{1/2}$ = 6 h

t = 3.0 days

Required

the activity of the sample after 3.0 days (A)

Analysis and Solution

3.0 days = 72 hours = 12(6 hours) = 12 half-lives for the radioactive sample.

Combine and apply the relations $A = -\lambda N$ and $N = N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$ to determine the activity after 12 half-lives.

$$
\begin{aligned}
A &= -\lambda N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}\\
&= \left(0.50\times10^{6}\ \text{Bq}\right)\left(\frac{1}{2}\right)^{12}\\
&= 122\ \text{Bq}
\end{aligned}
$$

Paraphrase

After 3.0 days, the activity of the sample will have dropped to only 122 Bq.

40. ***Given***

$$\frac{N}{N_0} = 12.5\%$$

Required

age of cave painting (t)

Analysis and Solution

12.5% = $\frac{1}{8}$

Since $\frac{1}{8} = \frac{1}{2}\times\frac{1}{2}\times\frac{1}{2} = \left(\frac{1}{2}\right)^3$, the sample is three half-lives old.

From a source, the half-life of carbon-14 is 5730 years.

Since the sample is three half-lives old,

$$
\begin{aligned}
\frac{t}{t_{1/2}} &= 3\\
t &= 3 \times 5730\ \text{years}\\
&= 17\ 190\ \text{years}\\
&= 1.72\times10^{4}\ \text{years}
\end{aligned}
$$

Paraphrase

The cave painting is approximately 1.72×10^{4} years old.

41. ***Given***

Carbon-12 fuses with an alpha particle to form oxygen-16.

Required

energy released (ΔE)

Analysis and Solution

The fusion process should produce a nucleus with a higher net binding energy and a release of energy. To determine the energy released, calculate the mass defect between carbon-12 and helium, and oxygen-16:

$$\Delta m = m_{{}^{12}_{6}\text{C}} + m_{{}^{4}_{2}\text{He}} - m_{{}^{16}_{8}\text{O}}$$

$$
\begin{aligned}
\Delta m &= 12.000\ 000\,\text{u} + 4.002\ 603\,\text{u} - 15.994\ 915\ \text{u}\\
&= 0.007\ 688\,\text{u}
\end{aligned}
$$

Convert this mass to energy by multiplying by 931.5 MeV/u.

$$\Delta E = 0.007\ 688\ \text{u} \times 931.5\ \frac{\text{MeV}}{\text{u}}$$
$$= 7.161\ \text{MeV}$$

Paraphrase

The fusion of carbon into oxygen will release 7.161 MeV of energy per reaction.

42. ***Given***

$${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{1}\text{H} + \text{p}$$

Required

energy released (ΔE)

Analysis and Solution

Calculate the mass defect for this reaction in atomic mass units and then convert to energy units. Use the equation

$$\Delta m = 2m_{\text{deuterium}} - m_{\text{tritium}} - m_{\text{p}}$$
$$\Delta m = 2(2.014\ 102\ \text{u}) - 3.016\ 049\ \ \text{u} - 1.007\ 825\ \text{u}$$
$$= 0.004\ 330\ \text{u}$$
$$\Delta E = 0.004\ 330\ \text{u} \times 931.5\ \frac{\text{MeV}}{\text{u}}$$
$$= 4.033\ \text{MeV}$$

Paraphrase

The fusion of two deuterium nuclei into a tritium nucleus and a proton releases 4.033 MeV of energy per fusion reaction.

43. (a) According to the standard model, a neutron contains one up quark and two down quarks.

(b) u + d + d = (+2/3) + (–1/3) + (–1/3) = 0

44. (a) ***Given***

r = 1 fm = 1 × 10^{-15} m

Required

electrostatic force (F_{e})

Analysis and Solution

Use the coulomb force law, $F_{\text{e}} = \frac{kq_1q_2}{r^2}$, where $q_1 = q_2 = 1.60 \times 10^{-19}$ C, $k = 8.99 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$, $r = 1 \times 10^{-15}$ m

$$F_{\text{e}} = \frac{(8.99 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})^2}{(1 \times 10^{-15}\ \text{m})^2}$$
$$= 230\ \text{N}$$
$$= 2 \times 10^2\ \text{N}$$

Paraphrase

The electrostatic force of repulsion between the protons is 2×10^2 N .

(b) ***Given***

d = 1 fm = 1 × 10^{-15} m

Required

potential energy (PE)

Analysis and Solution

Use the equation $\text{PE} = \dfrac{kq_1q_2}{d}$.

$$\text{PE} = \frac{(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2}{1\times10^{-15}\ \text{m}}$$
$$= 2\times10^{-13}\ \text{J}$$

Paraphrase

The potential energy of the protons is $2\times10^{-13}\ \text{J}$.

(c) The strong nuclear force causes the protons to stick together in the nucleus. It compensates for the repulsion produced by the electrostatic force.

Extensions

45. ***Given***

Hydrogen atoms ionize on collision.

Required

minimum speed (v)

Analysis and Solution

It takes 13.6 eV to ionize a hydrogen atom, so each atom would require at least 13.6 eV of kinetic energy to ionize. Use the equation $E_\text{k} = \frac{1}{2}mv^2$. First convert 13.6 eV to joules. The mass of a hydrogen atom (proton) is $1.67\times10^{-27}\ \text{kg}$.

$$E_\text{k} = \left(13.6\ \cancel{\text{eV}}\right)\left(1.60\times10^{-19}\ \frac{\text{J}}{\cancel{\text{eV}}}\right)$$
$$= 2.176\times10^{-18}\ \text{J}$$

$$v = \sqrt{\frac{2E_\text{k}}{m}}$$
$$= \sqrt{\frac{2\left(2.176\times10^{-18}\ \text{J}\right)}{1.67\times10^{-27}\ \text{kg}}}$$
$$= 5.10\times10^{4}\ \text{m/s}$$

Paraphrase

The hydrogen atoms must be moving with speeds of at least 51 km/s to completely ionize on impact.

46. (a) A proton absorbs a photon, which then emits a neutral pion.

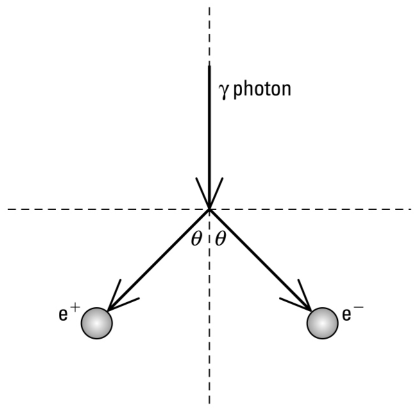
(b) The gamma ray must have an energy equivalent to the mass-energy of the neutral pion. In Table 17.3, the mass of the neutral pion is given as 135 MeV. So, the energy of the gamma-ray photon must be at least 135 MeV.

47. A nuclear decay can only happen if the mass of the daughter nucleus is less than the mass of the parent nucleus. In the case of β^+ decay, the mass of the daughter nucleus decreases because the emitted positron and neutrino carry kinetic energy that came from the mass-energy of the nucleus. This release of energy explains the conservation of mass-energy in this decay.

48. To conserve momentum, the electron and positron together must have the same momentum as the 5.0-GeV photon.

Since $p = \dfrac{h}{\lambda} = \dfrac{E}{c}$, the momentum of the photon is $\dfrac{5.0\ \text{GeV}}{c} = 2.7\times10^{-18}\ \text{N}\cdot\text{s}$.

As the diagram below shows, the electron and positron must travel in paths that are symmetric with respect to the direction of the photon. If the original direction of the photon is the *y*-axis, the electron and positron must travel as shown, such that the total momentum in the *x*-direction is zero.



49. ***Given***

Hydrogen atoms for which the attraction between the proton and electron is due to gravitation alone

Required

size of the hydrogen atom (r)

Analysis and Solution

The electron has a ground-state energy of –13.6 eV, which means that the total energy of the electron is –13.6 eV or 2.18 × 10^{-18} J. To solve for r, use the equation

$$E_{\text{total}} = -\frac{Gm_{\text{p}}m_{\text{e}}}{2r}$$

The mass of a proton is 1.67×10^{-27} kg and that of an electron is 9.11×10^{-31} kg.

Since you only want the radius, r, you can ignore the negative sign in the equation for gravitational force, or take and absolute value to obtain

$$\begin{aligned} r &= \left| -\frac{Gm_{\text{p}}m_{\text{e}}}{2E_{\text{total}}} \right| \\ &= \frac{(6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2)(1.67 \times 10^{-27}\ \text{kg})(9.11 \times 10^{-31}\ \text{kg})}{2(2.18 \times 10^{-18}\ \text{J})} \\ &= 2.33 \times 10^{-50}\ \text{m} \end{aligned}$$

Paraphrase

If you tried to use the gravitational force to explain the structure of a hydrogen atom, the answer implies that the size of the atom would be much, much less than the size of the nucleus of the atom!

50. (a) ***Given***

m_{K} = 0.40 g = 39.1 u

0.012% K is radioactive

$\lambda = 1.8 \times 10^{-17}\ \text{s}^{-1}$

Required

activity (A)

Analysis and Solution

The number of potassium atoms in a 0.40-g banana is:

$$N = \frac{(0.40\ \cancel{\text{g}})\left(\frac{1\ \cancel{\text{kg}}}{1000\ \cancel{\text{g}}}\right)}{\left(39.10\ \frac{\cancel{\text{u}}}{\text{atom}}\right)\left(1.67\times10^{-27}\ \frac{\cancel{\text{kg}}}{\cancel{\text{u}}}\right)}$$

$$= 6.126\times10^{21}\ \text{atoms}$$

The number of ${}^{40}_{19}\text{K}$ atoms is:

$$6.126\times10^{21}\ \text{atoms}\times 0.000\ 12 = 7.351\times10^{17}\ \text{atoms}$$

The activity of the banana is:

$$\begin{aligned} A &= -\lambda N \\ &= \left(-1.8\times10^{-17}\ \text{s}^{-1}\right)\left(7.351\times10^{17}\right) \\ &= -13\ \text{s}^{-1} \\ &= -13\ \text{Bq} \end{aligned}$$

Paraphrase

The activity of the banana is 13 Bq.

(b) With an activity of only 13 Bq, an average banana's radioactivity is far below naturally occurring levels. Your banana is both safe and good for you.

51. (a) ***Given***

radiation = 1.25 mGy/h

d = 1.0 m

RBE = 2

Required

Compare the level of the spill to the average background level.

Analysis and Solution

Convert Gy to Sv by using the relation dosage (Sv) = RBE × dosage (Gy)

The radiation level is 2 × 1.25 mGy/h = 2.50 mSv/h

Calculate the total yearly dosage by multiplying the hourly radiation rate by one year. Compare this value to the annual background dosage of 400 μSv.

The annual dosage would be

$$\begin{aligned} 2.50\ \frac{\text{mSv}}{\cancel{\text{h}}} \times 365.25\ \cancel{\text{d}} \times 24\ \frac{\cancel{\text{h}}}{\cancel{\text{d}}} &= 2.19\times10^{4}\ \text{mSv} \\ &= 21.9\ \text{Sv} \end{aligned}$$

Paraphrase

This level is much higher than the average background level of 400 μSv, or 4×10^{-4} Sv.

(b) ***Given***

radiation = 0.1 mSv/year

d = 1.0 m

Required

distance at which the radiation level drops below 0.1 mSv/year (r)

Analysis and Solution

Gamma radiation levels decrease according to the inverse square law (see 16-1 Inquiry Lab: Radiation Intensity) because gamma radiation is a form of electromagnetic radiation. Use this law to determine the distance at which the radiation level of the spill will equal 0.1 mSv/year.

If exposure varies inversely as r^2, the distance at which the dosage drops to 0.1 mSv/year is:

$$\left(2.19\times10^4\ \cancel{\text{mSv}}\right)(1.0\text{ m})^2 = \left(0.1\ \cancel{\text{mSv}}\right)r^2$$

$$r = 468\text{ m}$$

Paraphrase

The annual absorbed dose would decrease to 0.1 mSv at 468 m from the spill.

(c) If a safe distance from the spill is greater than 468 m, this description is fair because this spill is dangerous!

52. (a) When matter and anti-matter combine, there is a complete conversion of mass into energy—no particle or particles are left behind. A fusion process, on the other hand, produces a new, heavier particle and may (or may not) release energy.

(b) Fusion of hydrogen into helium releases approximately 24.67 MeV of energy (see the table in section 16.4). To determine the energy released when two protons and two anti-protons combine, calculate the energy equivalence of the two protons and anti-protons. It is easiest to use atomic mass units and the conversion factor 1 u = 931.5 MeV.

Energy released = 4(1.007 276 u)(931.5 MeV/u) = 3753 MeV

Therefore, the energy released during a matter-antimatter reaction would be more than 150 times more powerful than nuclear fusion!

(c) Antimatter requires a great deal of energy to produce and it can currently only be produced in small amounts. Also, it would annihilate the walls of any container of regular matter into which it was placed.

53. *Given*

P = 10 MWh

efficiency = 20%

Required

mass of deuterium and tritium (m)

Analysis and Solution

First, determine how much energy is released per reaction.

The energy released per reaction can be found by using

$$\begin{aligned} m_{\text{deuterium}} + m_{\text{tritium}} - m_{\text{helium}} - m_{\text{neutron}} &= 2.014\ 102\text{ u} + 3.016\ 049\text{ u} - 4.002\ 603\text{ u} - 1.008\ 665\text{ u} \\ &= 0.018\ 883\text{ u}\times 931.5\text{ MeV/u} \\ &= 17.59\text{ MeV} \end{aligned}$$

Each reaction releases 17.59 MeV of energy.

Divide this amount into the total energy required (10 MWh).

10 MWh = $(1.0 \times 10^7$ J/s × 3600 s) = 3.6×10^{10} J = 2.3×10^{23} MeV

The number of reactions required to release this amount of energy is

$$\frac{2.3\times10^{23}\text{ MeV}}{17.59\text{ MeV}} = 1.3\times10^{22}$$

Since the process is only 20% efficient, the total number of fusion reactions needed is

$$\frac{1.3 \times 10^{22}}{0.20} = 6.5 \times 10^{22}$$

This answer means that 6.5×10^{22} atoms of deuterium and 6.5×10^{22} atoms of tritium are needed.

The mass of deuterium is

$$\begin{aligned}(2.014\ 102\ \text{u})\left(1.660\ 539 \times 10^{-27}\ \text{kg/atom}\right)\left(6.5 \times 10^{22}\ \text{atoms}\right) &= 2.2 \times 10^{-4}\ \text{kg} \\ &= 0.22\ \text{g}\end{aligned}$$

The mass of tritium is

$$\begin{aligned}(3.016\ 049\ \text{u})\left(1.660\ 539 \times 10^{-27}\ \text{kg/atom}\right)\left(6.5 \times 10^{22}\ \text{atoms}\right) &= 3.3 \times 10^{-4}\ \text{kg} \\ &= 0.33\ \text{g}\end{aligned}$$

Paraphrase

The annual energy needs of an average house could be supplied by the fusion of less than one gram of deuterium and tritium.

Skills Practice

54. ***Given***

$N = 6\%(N_0)$

$t = 2$ years

Required

half-life $\left(t_{1/2}\right)$

Analysis and Solution

Use the equation $N = N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$. Re-write it in the fraction form $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$, where

$\frac{N}{N_0} = 6\% = 0.06.$

$$0.06 = \left(\frac{1}{2}\right)^x$$

Use trial-and-error to solve for x.

$$x = 4.05 = \frac{t}{t_{1/2}}$$

Since $t = 2$,

$$t_{1/2} = \frac{2}{4.05} = 0.5$$

Paraphrase

The half-life of this isotope is 0.5 years.

55. Use atomic notation to write ${}^{10}_{5}\text{B} + {}^{4}_{2}\alpha \rightarrow {}^{10+3}_{5+1}\text{Y} + {}^{1}_{1}\text{p}$. Both charge and nucleon number are conserved. The new nucleus, with a charge of 6 and a mass of 13, is carbon-13, ${}^{13}_{6}\text{C}$.

56. ***Given***

$E_1 = –5.1$ eV

$E_2 = –6.17$ eV

Required
whether a photon is absorbed or emitted (ΔE)
the wavelength of the photon (λ)
Analysis and Solution
To determine whether a photon is absorbed or emitted, calculate $\Delta E = E_{\text{final}} - E_{\text{initial}}$.
If $\Delta E > 0$, then the electron has gained energy by absorbing the photon. If $\Delta E < 0$, the electron has lost energy by emitting a photon.

$$\begin{aligned}\Delta E &= E_{\text{final}} - E_{\text{initial}} \\ &= -6.7 \text{ eV} - (-5.1 \text{ eV}) \\ &= -1.6 \text{ eV}\end{aligned}$$

The answer is negative, so the electron has emitted energy in the form of a photon.
To determine the wavelength of the photon, substitute the value you calculated for energy into the equation $\Delta E = \frac{hc}{\lambda}$.
The wavelength of the photon is

$$\begin{aligned}\lambda &= \frac{hc}{\Delta E} \\ &= \frac{\left(6.63\times10^{-34}\ \cancel{\text{J}}\cdot\cancel{\text{s}}\right)\left(3.00\times10^{8}\ \frac{\text{m}}{\cancel{\text{s}}}\right)}{\left(1.6\ \cancel{\text{eV}}\right)\left(1.60\times10^{-19}\ \frac{\cancel{\text{J}}}{\cancel{\text{eV}}}\right)} \\ &= 7.77\times10^{-7} \text{ m} \\ &= 777 \text{ nm}\end{aligned}$$

Paraphrase
In the transition between the initial and final energy levels, the electron loses energy in the form of a 777-nm photon.

57. To find the energy produced by 0.250 u of matter, use the conversion factor 1 u = 931.5 MeV.

$$0.250 \text{ u} \times 931.5\ \frac{\text{MeV}}{\text{u}} = 233 \text{ MeV}$$

Since 1 eV = 1.60×10^{-19} J,

$$\left(233\times10^{6}\ \cancel{\text{eV}}\right)\left(1.60\times10^{-19}\ \frac{\text{J}}{\cancel{\text{eV}}}\right) = 3.73\times10^{-11} \text{ J}$$

58. To find the radius of a hydrogen atom in the n = 2 state, use the equation $r_n = r_1 n^2$, where $r_1 = 5.29\times10^{-11}$ m.

$$\begin{aligned}r_2 &= r_1(2)^2 \\ &= (5.29\times10^{-11} \text{ m})\times 4 \\ &= 2.12\times10^{-10} \text{ m}\end{aligned}$$

59. (a) The energy of an electron is given by the expression $E_n = -\frac{13.6}{n^2}$ eV. Therefore, an electron in the n = 2 state has less energy than when it is in the n = 3 state.

(b) The energy difference between the states is $E_{3-2} = -13.6\left(\frac{1}{3^2} - \frac{1}{2^2}\right) = 1.89 \text{ eV}$.

60. ***Given***

$^{24}_{12}\text{Mg}$

Required

binding energy (E_b)

Analysis and Solution

From $^{24}_{12}\text{Mg}$,

$Z = 12$

$N = 24 - 12 = 12$

From a table of atomic masses, the mass of magnesium-24 is 23.985 042 u.

Calculate the mass defect using the equation $\Delta m = Zm_{^1_1\text{H}} + Nm_\text{neutron} - m_\text{atom}$.

$$\begin{aligned}\Delta m &= Zm_{^1_1\text{H}} + Nm_\text{neutron} - m_\text{atom} \\ &= 12(1.007\ 825\ \text{u}) + 12(1.008\ 665\ \text{u}) - 23.985\ 042\ \text{u} \\ &= 0.212\ 838\ \text{u}\end{aligned}$$

Determine the energy equivalence using 1 u = 931.5 MeV.

The binding energy of magnesium-24 is

$$0.212\ 838\ \text{u} \times 931.5\ \frac{\text{MeV}}{\text{u}} = 198.3\ \text{MeV}$$

Paraphrase

The binding energy for $^{24}_{12}\text{Mg}$ is 198.3 MeV.

61. $? \rightarrow {}^{14}_{7}\text{N} + \text{e}^- + \bar{\nu}$

This equation represents is a β^- decay, so use the form $^{A}_{Z}\text{X} \rightarrow {}^{A}_{Z+1}\text{Y} + \text{e}^- + \bar{\nu}$.

Thus, the reaction is $^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + \text{e}^- + \bar{\nu}$. The parent nucleus is, therefore, carbon-14.

62. From Table 17.5 in the SE, the up quark (u) has a charge of (+2/3) and the strange quark (s) has a charge of (–1/3). The charge of a particle of composition uus is (+2/3) + (+2/3) + (–1/3) = +1.

63. ***Given***

$N = 1.5 \times 10^{20}$ atoms

$\lambda = 3.5 \times 10^{-15}\ \text{s}^{-1}$

Required

activity (A)

Analysis and Solution

Use the equation $A = -\lambda N$.

$$\begin{aligned}A &= -\lambda N \\ &= -\left(3.5 \times 10^{-15}\ \text{s}^{-1}\right)\left(1.5 \times 10^{20}\right) \\ &= -5.25 \times 10^{5}\ \text{Bq}\end{aligned}$$

Paraphrase

The activity is 5.25×10^5 Bq.

Self-assessment

Students' answers in this section will vary greatly depending on their experiences, depth of understanding, and the depth of the research that they do into each of the topics.

