Pearson Physics Level 30
Unit VIII Atomic Physics: Chapter 17
Solutions

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Concept Check

Since neutrons have no charge, they do not create ions when passing through the liquid in a bubble chamber. Therefore, neutrons do not leave tracks in a bubble chamber. However, if a neutron collides with a charged particle or splits a nucleus, the collision will produce tracks that suddenly start or change direction. Analysis of these tracks can show that the neutron was involved in the collision.

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Example 17.1 Practice Problems

1. ***Given***

$r = 8.66 \times 10^{-4}$ m
$v = 4.23 \times 10^{5}$ m/s
$|\vec{B}| = 5.10$ T

Required

charge-to-mass ratio $\left(\frac{q}{m}\right)$

Analysis and Solution

The charge-to-mass ratio for a particle moving perpendicular to a magnetic field is $\frac{q}{m} = \frac{v}{|\vec{B}|r}$.

Substitute the given values into the equation.

$$\frac{q}{m} = \frac{4.23 \times 10^{5}\ \text{m/s}}{(5.10\ \text{T})(8.66 \times 10^{-4}\ \text{m})}$$

$$= \frac{4.23 \times 10^{5}\ \frac{\cancel{\text{m}}}{\cancel{\text{s}}}}{\left(5.10\ \frac{\text{kg}}{\text{A} \cdot \text{s}^{\cancel{2}}}\right)(8.66 \times 10^{-4}\ \cancel{\text{m}})}$$

$$= 9.58 \times 10^{7}\ \text{A} \cdot \text{s/kg}$$

$$= 9.58 \times 10^{7}\ \text{C/kg}$$

Paraphrase

The charge-to-mass ratio for the proton is 9.58×10^{7} C/kg.

2. ***Given***

$v = 3.2 \times 10^{5}$ m/s
$B = 1.2$ mT $= 1.2 \times 10^{-3}$ T

Required
radius of path (r)
Analysis and Solution
Since the particle is an electron, its charge-to-mass ratio is 1.8×10^{11} C/kg (from Example 17.1).
The equation for the charge-to-mass ratio for a particle moving perpendicular to a magnetic field is $\frac{q}{m} = \frac{v}{|\vec{B}|r}$.

Rearrange the equation to solve for radius.

$$r = \frac{v}{|\vec{B}| \times \frac{q}{m}}$$

$$= \frac{3.2 \times 10^5 \text{ m/s}}{(1.2 \times 10^{-3} \text{ T})(1.8 \times 10^{11} \text{ C/kg})}$$

$$= \frac{3.2 \times 10^5 \text{ m/}\cancel{\text{s}}}{\left(1.2 \times 10^{-3} \frac{\cancel{\text{kg}}}{\cancel{\text{A}} \cdot \cancel{\text{s}^2}}\right)\left(1.8 \times 10^{11} \frac{\cancel{\text{A}} \cdot \cancel{\text{s}}}{\cancel{\text{kg}}}\right)}$$

$$= 1.5 \times 10^{-3} \text{ m}$$

Paraphrase
The radius of the path of the electron is 1.5×10^{-3} m or 1.5 mm.

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Concept Check

You cannot tell for certain that momentum is conserved because the momentum of the incoming particle is not known, and other neutral particles could have been involved in the event.

17.1 Check and Reflect

Knowledge

1. In a cloud chamber, charged particles pass through a cooled supersaturated atmosphere, causing condensation or a liquid vapour trail. In a bubble chamber, charged particles pass through a hot liquefied gas, causing the gas to form bubbles or a gas trail.

2. (a) Electrons, protons, alpha particles, and any subatomic particles with a charge will leave tracks in a bubble chamber.

(b) Neutrons, photons, and any particles with no charge will not leave tracks in a bubble chamber.

3. (a) When charged particles travel perpendicular to an external magnetic field, they experience a deflecting force due to the motor effect, which causes them to travel in a curved path.

(b) The direction of deflection can reveal the charge on the particle, and the radius of the deflection can determine the mass, the amount of charge or the momentum of the particle.

Applications

4. Since X-ray photons do not have a charge, they cannot ionize gas molecules in the bubble chamber and, therefore, cannot leave a gas trail.

5. (a) By using either the right- or left-hand rule, you can deduce that the bottom particle is negatively charged and that the top particle is positively charged. For example, using the right-hand rule, point your thumb in the direction of motion of the particle (to the right) and point your fingers into the page for the direction of the magnetic field. Your palm, which represents the magnetic force, faces upward, toward the top of the page. Since the top particle deflected in this direction, it must be positively charged.

(b) To determine which particle is moving faster, you would need to know the radius of the arc, the strength of the external magnetic field, and the charge-to-mass ratio of the particle.

6. (a) Since the alpha particle is much heavier than the proton, it will deflect in an arc with a larger radius.

(b) Since the electron has a negative charge and the proton has a positive charge, they will deflect in different directions if they pass through a magnetic field. The proton is more massive than the electron, so the radius of its arc will be much larger.

7. (a) The incoming particle was an alpha particle because, in colliding with a helium nucleus, both deflecting particles are the same in mass and velocity (a helium nucleus is the same as an alpha particle). The x and y components of the momentum of the particle on the left will be equal to the x and y components of the momentum of the particle on the right.

(b) Use the right-hand rule. The thumb points toward the top left of the page, in the direction of charge motion, the deflecting magnetic force is to the left and down (toward the bottom of the page), and the direction of the magnetic field is into the page. If the particle on the left curves slightly downward, toward the bottom of the page, then it has a positive charge.

Extension

8. It is easier to produce an environment and sustain a trail with a superheated liquid in a bubble chamber than one with a supercooled gas in a cloud chamber.

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Concept Check

Since $r = \frac{vm}{|\vec{B}|q}$, the radius of the particle's path decreases as the particle slows down.

So, the particle in Anderson's photograph must have been moving downward (toward the bottom of the page). Applying the right-hand rule shows that this particle has a positive charge. The fingers point into the page, in the direction of the magnetic field. The thumb points toward the bottom of the page, in the direction of the charge's motion. The palm faces right, the direction in which the particle is being deflected in Figure 17.11.

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Concept Check

Since the positron and electron have equal masses and are travelling with equal speeds in opposite directions, their total momentum is zero. A single photon has momentum in the direction in which it is travelling. For momentum to be conserved, the collision must produce two identical photons travelling in exactly opposite directions.

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17.2 Check and Reflect

Knowledge

1. Antimatter has the same mass as its matter particle but the opposite charge.
2. Anderson photographed the track of a positron in a cloud chamber.
3. (a) The electromagnetic force is the strongest force over large distances.
(b) The gravitational force is the weakest force at nuclear distances.
4. (a)

Force	**Mediating Particle(s)**
gravitational force	graviton
electromagnetic force	photon
strong nuclear force	gluon
weak nuclear force	W^+, W^-, and Z^0

(b) Gravitons have not been detected at all.
5. X rays create images by passing X-ray photons through the body from an external source. PET scanners produce images from gamma photons that originate from the radioactive decay of an isotope within the body. So, having a PET scan is like being X-rayed from the inside out.

Applications

6. (a) The matter e^- is annihilated by its antimatter e^+ to produce energy photons.
(b) The law of conservation of momentum requires the production of two energy photons when an electron and a positron collide.
7. (a) Two protons will attract each other at distances smaller than the size of the nucleus, due to the strong nuclear force.
(b) Two protons will repel each other at distances that are larger than nuclear, due to the electromagnetic force.
8. (a) The originating particle has no track, so it must be either neutral or a photon.
(b) Since the direction of the particles created during the collision is to the right, the originating particle must have come from the left and travelled right.
(c) Using the right-hand rule, the bottom particle must be positively charged. Fingers point out of the page, in the direction of the magnetic field. The thumb points to the right, in the direction of charge motion. The palm faces toward the bottom of the page, in the direction of the magnetic force, so the positively charged particle is deflected toward the bottom of the page.
(d) Since the particles deflect in opposite directions in an external magnetic field, they must be oppositely charged. Also, since the original charge, prior to the creation of

the particle pairs, was zero, there must be a negative charged formed, according to the law of conservation of charge.

(e) $\gamma \rightarrow e^{+} + e^{-}$

$0 = 0$

The particles have equal masses and equal and opposite charges.

(f) Since the curvature of the paths is similar, the particles must have equal masses and equal and opposite charges to conserve momentum and energy. Therefore, it is likely that the interaction involves an antiparticle.

9. The helium nucleus contains two protons that are stable and attract each other with a tremendous strong nuclear force. If the electromagnetic force were stronger than the nuclear forces, the two protons would repel each other and the nucleus would decay.

Extension

10. The Casimir effect is a small attractive force that acts between two close parallel *uncharged* conducting plates. It is due to quantum vacuum fluctuations of the electromagnetic field.

Lamb shift—According to the hydrogen Schrodinger equation solution, the energy levels of the hydrogen atom's electron should depend only on the principal quantum number, *n*. In 1951, Willis Lamb discovered that this was not so: The 2*p*(1/2) state has a slightly lower energy than the 2*s*(1/2) state, resulting in a slight shift of the corresponding spectral line. This shift is known as the Lamb shift.

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Concept Check

The protons from a large accelerator can have much higher energy than those from radioactive decay. An accelerator can produce focused beams with large numbers of particles, and lets the experimenter control the direction and timing of the high-energy particles. Drawbacks of accelerators include high costs and long set-up times. Alpha particles from radioactive decays are vastly cheaper and simpler to use. However, these particles are emitted at random times and angles.

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17.3 Check and Reflect

Knowledge

1. To be able to approach the nucleus, the particles must have tremendously high energy to overcome the electrostatic forces of repulsion within the nucleus. To probe the nucleus, the particles require even more energy to overcome the strong and weak nuclear forces. For these reasons, physicists require extremely high-energy particles for studying the structure of nucleons.

2. Radioactive isotopes and cosmic rays are two natural sources of energetic particles.

3. High-energy primary cosmic rays cannot penetrate the atmosphere. They react with atoms in the atmosphere, producing less energetic secondary cosmic rays.

4. (a) In medicine, particle accelerators focus beams of X rays for destroying cancerous cells. Bombarding elements with particles from cyclotrons can produce radioactive isotopes for diagnostic techniques and radiation therapy.

(b) In industry, radioactive isotopes can be used for testing structural materials, modifying polymers, and implanting ions in semiconductors.

5. (a) Leptons do not interact via the strong nuclear force, whereas hadrons do.

(b) Baryons have more mass than mesons.

Applications

6. Alpha particles from the radioactive decay of polonium cannot be used because they are much too massive to attain the high energies required for probing the nucleus.

7. (a) ***Given***

$v = 0.01c$

Required

momentum (p)

kinetic energy (E_k)

Analysis and Solution

To find the momentum of the proton, use the equation $p = mv$.

$$\begin{aligned} p &= mv \\ &= \left(1.67\times10^{-27}\ \text{kg}\right)\left(0.01\times3.00\times10^{8}\ \text{m/s}\right) \\ &= 5\times10^{-21}\ \text{kg}\cdot\text{m/s} \end{aligned}$$

To find kinetic energy, use the equation $E_k = \frac{1}{2}mv^2$.

$$\begin{aligned} E_k &= \frac{1}{2}\left(1.67\times10^{-27}\ \text{kg}\right)\left(0.01\times3.00\times10^{8}\ \text{m/s}\right)^2 \\ &= 8\times10^{-15}\ \text{J} \end{aligned}$$

Paraphrase

The momentum of the proton is 5×10^{-21} kg·m/s and its kinetic energy is 8×10^{-15} J.

(b) ***Given***

$v = 5.0\times10^{5}$ m/s

Required

momentum (p)

kinetic energy (E_k)

Analysis and Solution

To find the momentum of the proton, use the equation $p = mv$.

$$\begin{aligned} p &= \left(1.67\times10^{-27}\ \text{kg}\right)\left(5.0\times10^{5}\ \text{m/s}\right) \\ &= 8.4\times10^{-22}\ \text{kg}\cdot\text{m/s} \end{aligned}$$

To find kinetic energy, use the equation $E_k = \frac{1}{2}mv^2$.

$$\begin{aligned} E_k &= \frac{1}{2}\left(1.67\times10^{-27}\ \text{kg}\right)\left(5.0\times10^{5}\ \text{m/s}\right)^2 \\ &= 2.1\times10^{-16}\ \text{J} \end{aligned}$$

Paraphrase

The momentum of the proton is 8.4×10^{-22} kg·m/s and its kinetic energy is 2.1×10^{-16} J.

8. (a) From $E = mc^2$,

$$E = 0.51100\ \frac{\text{MeV}}{c^2} \times c^2$$
$$= 0.51100\ \text{MeV}$$

The energy equivalent of the mass of an electron is 0.51100 MeV.

(b) $$3.097\ \frac{\text{GeV}}{c^2} \times \frac{1.7827 \times 10^{-27}\ \text{kg}}{1\ \frac{\text{GeV}}{c^2}} = 5.521 \times 10^{-27}\ \text{kg}$$

9. 1 u = 1.660 539 × 10^{-27} kg and 1 MeV/c^2 = 1.7827 × 10^{-30} kg, so

$$1\ \text{u} = \frac{1.660\ 539 \times 10^{-27}\ \text{kg}}{1.7827 \times 10^{-30}\ \frac{\text{kg}}{\text{MeV}/c^2}} = 931.5\ \text{MeV}/c^2$$

The conversion factor between atomic mass units and MeV/c^2 is 931.5.

Extensions

10. Stronger magnets can centripetally accelerate higher-energy particles. These particles can then be used to probe the structure of matter even deeper.

11. (a) In a cyclotron, the radius of charged particles increases with their speed, causing the particles to spiral toward the cyclotron's outer wall. Hence, they cross the gap between the two electrodes too late to be accelerated again by the electric field.

(b) Synchrocyclotrons synchronize with the motion of the particles by slowing the alteration rate of the electric field as the particles' speed increases.
Synchrotrons increase the magnetic field as the speed of the particles increases, thereby reducing the rate at which the radius of the particles' path increases.
TRIUMPH increases the strength of the magnetic field from the centre to the edges of the accelerator.

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17.4 Check and Reflect

Knowledge

1. The scattering of electrons off protons suggested that there were three centres within the proton.

2. Individual quarks probably cannot be observed because the strong nuclear force binds them very tightly in a particle. The energy needed to separate quarks is large enough to create new quarks or antiquarks. The new particles bind to the quark being separated before it can be observed on its own.

3. The quark composition of a proton is uud, and that of a neutron is udd.

4. Mesons contain a quark and an antiquark, whereas baryons contain three quarks.

5. Leptons do not interact by means of the strong nuclear force, whereas hadrons do. Hadrons are composed of quarks, whereas leptons are not.

6. The 12 particles are 6 leptons (electron, electron neutrino, muon, muon neutrino, tauon (tau), tauon (tau) neutrino) and 6 quarks (up, down, strange, charm, bottom, top).

Applications

7. (a) $\text{udd} \rightarrow \text{uud} + \text{e}^- + \bar{\nu}_e$

(b) $0 \rightarrow 1 + (-1) + 0$

$0 \rightarrow 0$

8. This beta decay is not possible because charge is not conserved. To conserve charge, the e^+ particle must be produced, not the e^- particle.

9. A proton decays into a neutron by means of the virtual mediating particle W^+.

Extension

10. If all the fundamental forces of nature could be combined into one grand unified theory, this theory would provide further corroboration that the universe originated at the Big Bang.

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Chapter 17 Review

Knowledge

1. In a bubble chamber, any disturbance, such as a charged particle, travelling through a supersaturated atmosphere causes ionization of the gas molecules, which in turn causes a condensation, creating a vapour trail.

2. **(a)** Charles Wilson built the first cloud chamber.

(b) Marietta Blau developed photographic technology consisting of a photographic plate coated with a thick emulsion containing silver bromide grains that led to the discovery of pions.

(c) Donald Glaser developed the first bubble chamber.

3. **(a)** In the early 1900s, the three fundamental building blocks of matter were thought to be the proton, electron, and neutron.

(b) The electron is still thought to be a fundamental particle.

4. The quantum mechanics combined with Einstein's theory of relativity predicted that each matter particle has an antimatter particle.

5. **(a)** The antimatter particle for the electron is the positron, which has the same mass as the electron but a positive charge.

(b) The antimatter particle for the proton is the antiproton, which has the same mass as the proton but a negative charge.

6. According to quantum field theory, all fundamental forces act over a distance through a virtual mediating particle. For example, the carrier of the electromagnetic force is the photon.

7. Pions are more massive than muons. There is only one type of muon and it has a negative charge. There are three types of pions—one that has a positive charge, one that has a negative charge, and one that is neutral. Muons are leptons, whereas pions are mesons.

8. Two advantages of the units MeV/c^2 are that the masses of subatomic particles are very small and these mass units omit the need for exponents. Also, these units are more convenient for equating mass and energy.

9. The diameter of an electron is less than 10^{-18} m and that of a proton is about 10^{-15} m.

10. An experiment that provided evidence for the existence of quarks was conducted in 1967 by Friedman, Kendall, and Taylor. It consisted of using the Stanford Linear Accelerator to beam extremely high-energy electrons at protons. The scattering pattern of electrons suggested three centres of mass and charge within the proton.

11. First, Millikan was using energies that are much, much too small to learn anything about nuclear processes or subatomic particles in the nucleus. Second, the standard model suggests that it is impossible to isolate quarks under the current conditions in the universe.

12. (a) Since there were six leptons, scientists suspected that there might be six quarks.

(b) The sixth quark is the top quark.

(c) A large accelerator was needed to attain the high energy required to probe for the sixth quark, which is 40 000 times more massive than the up quark.

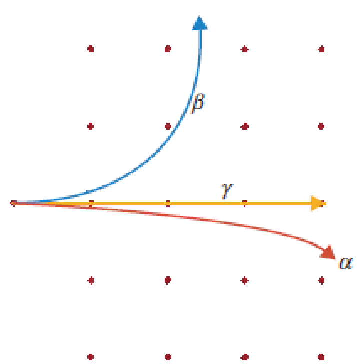
13. The quark composition of an antiproton is $\bar{u}\,\bar{u}\bar{d}$ and that of an antineutron is $\bar{u}\,\bar{d}\,\bar{d}$.

14. The standard model unites the electromagnetic force and the weak nuclear force into the electroweak force.

15. According to string theory, subatomic particles are tiny vibrating strings of mass-energy. Vibrations are quantized and each particle has a different mode of vibration.

Applications

16. Apply the right-hand rule and assume that the charge is moving to the right. Fingers point out of the page, in the direction of the magnetic field. The thumb points to the right, in the direction of charge motion. The palm faces downward (toward the bottom of the page), in the direction of the magnetic force. The alpha particle is deflected toward the bottom of the page, so it has a positive charge. The beta particle will therefore be deflected upward (toward the top of the page). Since gamma photons have no charge, they will not be deflected.



17. (a) The clockwise bend in the path of the proton suggests that the magnetic field must be oriented out of the page. You may check this answer by applying the right-hand rule. The thumb points toward the bottom of the page, in the direction of charge motion. The palm faces left, in the direction of the magnetic force, so the deflection is clockwise. Fingers point out of the page, in the direction of the magnetic field.

(b) Apply the laws of conservation of momentum and of energy to this collision. The kinetic energy of the original proton will be shared between the scattered proton and the hydrogen atom's nucleus (another proton), which implies that they will move at a slower speed than the original proton. The particles will all be positively charged.

(c) The small spiral tracks are likely due to electrons. They must be negatively charged because their direction of rotation is opposite to the direction of deflection of the proton. The spiral pattern suggests that the particles are losing energy.

18. **(a)** ${}^{18}_{9}F \rightarrow {}^{18}_{8}O + e^{+} + \upsilon_e$

(b) During β^{+} decay, a proton in a nucleus changes into a neutron. This change occurs because an up quark is turned into a down quark by means of the weak nuclear force. A positron and a neutrino are emitted from the nucleus during this process.

(c) When the positron meets an electron, they annihilate each other to produce two gamma rays according to the equation $e^{-} + e^{+} \rightarrow 2\gamma$. The gamma rays are emitted to the detector.

19. $176\ \cancel{\text{GeV}/c^2} \times 1.7827 \times 10^{-27} \dfrac{\text{kg}}{\cancel{\text{GeV}/c^2}} = 3.14 \times 10^{-25}\ \text{kg}$

20. **(a)** uus = +2/3e + (+2/3e) + (–1/3e) = +e

(b) The mass of this particle is approximately 83–138 MeV/c^2.

21. **(a)** Using the left-hand rule, the particle has a negative charge. Fingers point out of the page, in the direction of the magnetic field. The thumb points to the right, in the direction of charge motion. The palm faces toward the top of the page, in the direction of the magnetic force, which is the direction of deflection in the diagram.

(b) The initial radius of the particle's path is approximately 10 cm.

(c) ***Given***

$|\vec{B}| = 1.2\ \text{T}$

$r = 0.10\ \text{m}$

$q = 1.60 \times 10^{-19}\ \text{C}$

Required

momentum (p)

Analysis and Solution

From the equation $\dfrac{mv^2}{r} = |\vec{B}|qv$, solve for r and simplify to get $r = \dfrac{mv}{|\vec{B}|q} = \dfrac{p}{|\vec{B}|q}$.

Then, solve for p to obtain the magnitude of the momentum.

$$\begin{aligned} p &= |\vec{B}|qr \\ &= (1.2\ \text{T})(1.60 \times 10^{-19}\ \text{C})(0.10\ \text{m}) \\ &= 1.9 \times 10^{-20}\ \text{N} \cdot \text{s} \end{aligned}$$

Paraphrase

The momentum of the electron is $1.9 \times 10^{-20}\ \text{N} \cdot \text{s}$.

(d) The inward spiral suggests that the particle is losing energy, and hence momentum.

(e) The short tracks are likely secondary, weak collisions between the negative charge and other hydrogen nuclei in the bubble chamber.

Extension

22. Pauli's exclusion principle deals with the odd property of spin of electrons and many other subatomic particles. An electron can have only two possible values of spin. Because this idea is so similar to the macroscopic idea of a spinning object, physicists state that an electron can have either a spin-up or a spin-down state. Pauli's exclusion principle states that, in any quantum state, there can be no more than one electron in a given spin state at any given time, which means that only two electrons, spin up and spin down, can share a common quantum state.

