Chapter # 15

Gravitation

Multiple choice Questions

Encircle the correct option.

1. **Two identical balls of masses 1 kg each having distance of 1 m between their centers then gravitational force between them is:**
   A. 6.67×10^{-9} N **B. 6.67×10^{-11} N** C. 6.67×10^{11} N D. 6.67×10^{-13} N
2. **Gravitational force between two objects is 'F'. If masses of two bodies are doubled and distance between their centers is reduced to half, then gravitational force is:**
   A. F B. 4F C. F/4 **D. 16F**
3. **The value of 'g' at height of 1500 km above the surface of Earth in m s^{-2} is:**
   A. 0 **B. 6.4** C. 9.8 D. 12.2
4. **As we go deeper under the surface of earth, the value of gravitational field strength 'g':**
   A. increase **B. decrease** C. remains constant D. become negative
5. **If we consider Earth as perfect sphere and ignore the presence of a resistance. What will be the orbital velocity to launch a satellite in a circular orbit just above the surface at r = 6.4×10^{6} m:**
   A. 0 km s^{-1} B. 1.19 km s^{-1} C. 3.07 km s^{-1} **D. 7.9 km s^{-1}**
6. **When a satellite is put into a higher circular orbit, it's kinetic energy:**
   A. increases **B. decreases** C. is zero D. remains the same
7. **The orbital velocity of geostationary satellite is:**
   A. 0 km s^{-1} B. 1.19 km s^{-1} **C. 3.07 km s^{-1}** D. 7.9 km s^{-1}
8. **The minimum number of geostationary satellites for complete global coverage is:**
   A. 1 B. 2 **C. 3** D. 4
9. **When an object moves away from a massive body, it's gravitational potential energy:**
   A. increases B. decreases C. remains constant D. become zero
10. **The value of gravitational potential at an altitude of 35700 KM about the earth's surface, where communication satellites orbit the earth is approximately:**
    A. - 94.7 M J kg^{-1} B. - 62.3 M J kg^{-1} C. 947.11 J kg^{-1} D. 947.11 J kg^{-1}
    No right option provided, so right is **-9.5×10^{6} J kg^{-1}.**

Short Questions

1. **Why can gravitation not account for the formation of molecules?**
   Gravity is too weak to be the primary force behind molecular formation. While gravity plays a crucial role in larger structures like stars and planets, it's insignificant compared to the electrical forces that govern interactions at the atomic and molecular level. At these scales, electromagnetic forces dominate, and the attractive force between atoms is due to the sharing or transfer of electrons, not gravity.
2. **Why don't two books on your desk attract each other gravitationally, despite Newton's law of gravitation?**

While Newton's law of gravitation applies to all objects with mass, the gravitational force between two books on a desk is incredibly small due to small masses. Everything in universe attracts anything around it. Even two books do, but the force acting between two bodies is negligible. We find the force of attraction between two bodies by this formula:
$F = G M m / r^2$.
Where F is the force of attraction between the two bodies, G is the gravitational constant (6.67×10^{-11} N m^2 kg^{-2}).

3. **Why does an apple fall towards Earth due to gravity, while earth does not move towards the Apple?**
While both the apple and the Earth are attracted to each other due to gravity, the Earth doesn't noticeably move towards the apple because of its much larger mass. Newton's Second Law of Motion (F=ma) explains this: the same force (gravity) causes a much smaller acceleration in a larger mass.
4. **Can gravitational field strength be negative? Explain.**
Yes, gravitational field strength can be negative. It's a vector quantity, and its sign indicates the direction of the gravitational force relative to a chosen coordinate system. When dealing with attractive gravitational forces, like those between celestial bodies, it's common to define the field as negative when pointing towards the center of mass of the attracting body. In my revision guide the gravitational field strength is given as $g=GM/r^2$ whereas gravitational potential is $V=-GM/r$. where the direction of g in decreasing potential V.
5. **What factors determine the strength of gravitational field around a planet?**
According to formula of gravitational field strength $g=GM/r^2$,
The strength of a planet's gravitational field is primarily determined by its mass and radius. A larger mass results in a stronger gravitational field, while a larger radius (for a given mass) results in a weaker field.
6. **If two planets have the same mass but different radii. How would they are gravitational field strength compare?**
If two planets have the same mass, but different radii, where field strength is $g \propto 1/r^2$.
If one has a smaller radius, the smaller planet will have a stronger gravitational field strength at its surface. This is because gravitational field strength is inversely proportional to the square of the radius of the planet.
7. **Why satellites in higher orbits have lower orbital velocities?**
Satellites in higher orbits have lower orbital velocities because $v = \sqrt{\frac{GM}{R}}$ where larger the distance smaller will be velocity. And also, the gravitational force weakens with distance. To maintain a stable orbit, a satellite must balance its forward velocity with the gravitational pull of the object it's orbiting. At higher altitudes, the gravitational force is weaker, requiring less velocity to counteract it and maintain a stable orbit.
8. **How does the mass of the earth affect the orbital velocity required for a satellite to stay in orbit?**

The orbital velocity required for a satellite to stay in orbit is directly proportional to the square root of the mass of the Earth ($v = \sqrt{\frac{GM}{R}}$), meaning a more massive Earth would require a higher orbital velocity for a satellite at the same distance. Conversely, the orbital velocity is inversely proportional to the square root of the orbital radius, so a larger orbit requires a slower orbital velocity.

9. **What are the primary benefits of using geostationary satellites for communication purpose compared to other type of set satellite orbits?**
   Geostationary satellites offer unique advantages for communication due to their fixed position relative to Earth, enabling continuous coverage and simplified ground station infrastructure. This means that they stay above the same point on the Earth's surface. This is why satellite television dishes can be set in a certain position and do not need to move
10. **There are limited number of stable geostationary orbits available. So, what measures do we take to handle the possible rise in the number satellites? Do we have any international rule or agreements to address this?**
    To manage the increasing number of satellites in geostationary orbit, several measures are being implemented, including improved orbital station-keeping techniques, international agreements on orbital slots, and end-of-life disposal strategies. These measures aim to prevent collisions, interference, and ensure the long-term sustainability of the geostationary orbit.
    International organizations like the International Telecommunication Union (ITU) allocate orbital slots and frequencies, and establish guidelines to minimize interference and ensure fair access to the geostationary orbit.
11. **Is it possible for an object's gravitational potential energy to become negative? If so, what does this means for the object's motion?**
    Yes, an object's gravitational potential energy can be negative. $U=-GMm/r$, it occurs when the reference point for zero potential energy is chosen at an infinite distance from the gravitational source, making any finite distance have negative potential energy. This doesn't mean the object has negative energy, but rather it reflects the energy required to pull the object away from the source of gravity to infinity.
12. **How the gravitational potential energy of two-point messes is related to concept of gravitational potential?**
    Gravitational potential energy and gravitational potential are closely related concepts. Gravitational potential energy (U) is the energy stored in a system of two or more masses due to their gravitational interaction. It's the potential energy associated with the force of gravity between the masses. Gravitational potential (V), on the other hand, is the potential energy per unit mass at a given point in a gravitational field. Essentially, the gravitational potential energy of a system is the product of the mass of one object and the gravitational potential at its location due to the other object.

Numerical

1. **Find the mass of the earth by considering a scenario where a small object is placed on the earth's surface such that distance between their centers is equal to earth radius, i.e., 6.4×10^6 m.**

   where:
   gravitational constant= G = 6.674×10^{-11} N m^2/kg^2
   radius of the Earth= R = 6400km=6.4×10^6 m
   mass of the Earth= M =?
   $g=GM/R^2$
   Now, substituting the values into the formula:

   $M= gR^2/G$
   $M= (9.8)(6.4\times10^6)^2/6.674\times10^{-11}$
   $M= 6\times10^{24}$ kg

2. **Alpha Centauri is a binary star system with two stars: Alpha Centauri A and Alpha Centauri B. The mass of Alpha Centauri A is 2.19×10^{30} kg and Alpha Centauri B is 1.81×10^{30} kg, then attract each other with the force of 2.24×10^{25} N. What is the distance between the two stars?**

   mass of Alpha Centauri A = M_A= 2.19×10^{30} kg
   mass of Alpha Centauri B = M_B= 1.81×10^{30} kg
   force of attraction = F = 2.24×10^{25} kg

   Now, substituting the values into the formula:

   $F= G\, M_A\, M_B /r^2$
   $r= \sqrt{\frac{F}{G\, MA\, MB}} = \sqrt{\frac{(2.24\times10^{\wedge}25\,)}{(6.674\times10^{\wedge}-11)(2.19\times10^{\wedge}30)\,(1.81\times10^{\wedge}30)}}$ = 3.43×10^{12} m

3. **What will be the value of 'g' on an exoplanet (a planet outside of solar system) whose mass is Five time the mass of earth and its radius is twice the radius of Earth?**
   where:
   gravitational constant= G = 6.674×10^{-11} N m^2/kg^2
   radius of the planet = R' =2 times radius of the earth (R' = 2R)
   mass of the planet = M' = 5 times mass of the Earth (M' = 5M)
   gravity on earth = $g=GM/R^2$
   gravity on planet = $g' = GM'/R'^2$
   Now, substituting the values into the formula:

   $g' = GM'/R'^2$ $g' = G5M/(2R)^2$ $g' = 5/4\, g$
   $g'=5/4(9.8) = 12.25$ m s^{-2}

4. **The hobble space telescope is in a circular orbit 613 km about the Earth's surface. The average radius of earth is 6.37×10^6 m and the mass of earth is 5.97×10^{24} kg.**

   (a) what is the speed of telescope in its orbit?

(b) what is the period of telescope's orbit?

where:
gravitational constant= G = 6.674×10^{-11} N m^2/kg^2

height of hobble space telescope h = 613 km

total distance from center of earth = r = R+h = 6370+613 = 6983 km

r = 6.983×10^6 m   m =5.97×10^{24} kg
(a) speed of telescope in its orbit

v = $\sqrt{\frac{Gm}{r}}$ = v = $\sqrt{\frac{(6.674\times10^{\wedge}-11)(5.97\times10^{\wedge}24)}{6.983\times10^{\wedge}6}}$ = 7550 m s^{-1}

(b) period of telescope's orbit

T = S/v   T = 2πr/v   T = 2π(6.983×10^6)/7550 = 5807 s

5. **You want to launch a satellite around planet Mars at an altitude of 100 km above its surface. Mars as a mass of 6.42×10^{23} kg and has a radius of 3.39×10^6 m, calculate its orbital velocity.**

   where:
   gravitational constant= G = 6.674×10^{-11} N m^2/kg^2

   altitude of planet h = 100 km

   total distance from center of planet = r = R+h = 3390+100 = 3490 km

   r = 3.49×10^6 m   m =6.42×10^{23} kg
   Orbital velocity

   v = $\sqrt{\frac{Gm}{r}}$ = v = $\sqrt{\frac{(6.674\times10^{\wedge}-11)(5.97\times10^{\wedge}23)}{3.49\times10^{\wedge}6}}$ = 3.4 km s^{-1}

6. **An asteroid orbits the sun 8.35 x 10^{11} m from it. (a) how fast must the asteroid travel to maintain its circular orbit around the sun? (b) how long will it take the asteroid to orbit the sun?**

   where:
   gravitational constant= G = 6.674×10^{-11} N m^2/kg^2

   asteroid orbits = r = 8.35 x 10^{11} m

   mass of sun= m =1.99×10^{30} kg
   (a) orbital velocity

$v = \sqrt{\frac{Gm}{r}} = v = \sqrt{\frac{(6.674\times10^{\wedge}-11)(1.99\times10^{\wedge}30)}{8.35\times10^{\wedge}11}} = 1.26\times10^4\ m\ s^{-1}$

(b) Time period

T = S/v　　T = 2πr/v　　$T = 2\pi(8.35 \times 10^{11})/\ 1.26\times10^4 = 4.16\times10^8$ s = 13.2 years

7. **Mars has a mass of 6.42×10^{23} kg and has a period of 88,642 second. What would be the radius of a stationary satellite for this planet.**
   Where:

   gravitational constant= $G = 6.674\times10^{-11}\ N\ m^2/kg^2$

   Mass of mars = m = 6.42×10^{23} kg
   Period of satellite = T = 88642 s
   radius of satellite = r =?

   Now, substituting the values into the formula:

   $r = (\frac{GMT^{\wedge}2}{4\pi^{\wedge}2})^{1/3}$　　$r=[(6.674\times10^{-11})(\ 6.42 \times 10^{23})(88642)^2\ /\ 4\pi^2]^{1/3}$
   r = 20428 km
8. **Calculate the potential energy of moon having mass 7.35×10^{22} kg, relative to earth with mass 5.98×10^{24} kg if the distance between their centers is 3.94×10^5 km.**
   Where:

   gravitational constant= $G = 6.674\times10^{-11}\ N\ m^2/kg^2$

   Mass of moon = m = 7.35×10^{22} kg
   Mass of earth = M = 5.98×10^{24} kg
   Distance between moon and earth = r = 3.94×10^5 km =3.94×10^8 m

   Now, substituting the values into the formula:

   Calculate the potential energy
   U = - GMm/r　　$U = -\ (6.674\times10^{-11})(\ 5.98 \times 10^{24})(\ 7.35 \times 10^{22})/(\ 3.94 \times 10^8)$
   $U = -\ 7.4\times10^{28}$ J
9. **A 50 kg whether satellite move in a circular orbit about the earth at an altitude of 1000 km. A similar 50 kg communication satellite is an altitude of 37000 km in circular orbit about the earth. Calculate the difference in the gravitational potential energy of two satellites in their respective orbits?**
   Where:

   gravitational constant= $G = 6.674\times10^{-11}\ N\ m^2/kg^2$

   Mass of earth = M = 5.98×10^{24} kg

(a) Mass of satellite 1 = m_1 = 50 kg

altitude of satellite 1 = h = 1000 km

total distance from center of earth = r_1 = R+h = 6400+1000 = 7400 km

$r_1 = 7.40\times10^6$ m

(b) Mass of satellite 2 = m_2 = 50 kg

altitude of satellite 2 = h = 37000 km

total distance from center of earth = r_2 = R+h = 6400+37000 = 43400 km

$r_2 = 4.34\times10^7$ m

Now, substituting the values into the formula:

Calculate the difference in the gravitational potential energy

$\Delta U = U_1 - U_2$ **ΔU**$= - GMm_1/r_1 -(- GMm_2/r_2)$ $\Delta U=GM(m_2/r_2 - m_1/r_1)$

ΔU $= (6.674\times10^{-11})(5.98 \times 10^{24})[(50/4.34\times10^7) - (50/7.40\times10^6)]$ =2.2 GJ

10. What is the change in gravitational potential energy of 64.5 kg astronauts, lifted from earth's surface into a circular orbit of altitude 4.40×10^2 km?

Where:

gravitational constant= G = 6.674×10^{-11} N m^2/kg^2

Mass of earth = M = 5.98×10^{24} kg

Mass of astronauts = m = 64.5 kg

altitude of astronauts = h = 4.40×10^2 km

total distance from center of earth = r = R+h = 6400+440 = 6840 km

$r = 6.84\times10^6$ m

Now, substituting the values into the formula:

Calculate the difference in the gravitational potential energy

$\Delta U = U_\infty - U_2$ **ΔU**$= 0 -(- GMm/r)$ $\Delta U = GMm/r$

$\Delta U =(6.674\times10^{-11})(5.98 \times 10^{24})(64.5)/(6.84\times10^6)$= 2.6×10^8 J

The end!

Exercise CH # 16

Encircle the correct option.

1. **Which of the following is the correct relation between pressure 'P' and density 'ρ' of the gas, at constant temperature?**

   A) $P \propto \frac{1}{\rho}$ B) $P \propto \frac{1}{\rho^2}$ C) $P \propto \rho$ D) $P \propto \rho^2$

Answer: A. $P \propto \frac{1}{\rho}$

(From the ideal gas law at constant T)

2. **Which of the following is correct formula for the root mean square speed of a molecule in a gas at absolute temperature T?**

   A) $c_{rms} = 1.5\sqrt{\frac{k\,t}{m}}$ B) $c_{rms} = 1.5\sqrt{\frac{m\,k}{T}}$ C) $c_{rms} = 1.73\sqrt{\frac{m}{k\,T}}$ D) $c_{rms} = 1.73\sqrt{\frac{k\,T}{m}}$

Answer: D. $c_{rms} = 1.73\sqrt{\frac{k\,T}{m}}$

3. **Which of the following motion of ideal gas molecules determines the temperature?**

   A) Translational motion B) Rotational motion
   C) Vibrational motion D) All types of motion

Answer: A. Translational motion

4. **Which of the following gas has the maximum root mean square velocity at the same temperature?**

   A) Oxygen B) Carbon dioxide C) Hydrogen D) Helium

Answer: C. Hydrogen

(Because RMS speed ; lower mass = higher speed)

5. **Real gases deviate from ideal behavior because gas molecules:**

   A) are colorless B) are spherical
   C) have intermolecular forces of attraction D) have high speeds

Answer: C. Have intermolecular forces of attraction

6. **The root mean square speed of gas at 27°C is $c_{r.m.s}$. If the temperature of gas is raised to 327°C, then which of the following will be root mean square speed of gas?**

   A) $\frac{1}{\sqrt{2}} C_{r.m.s}$ B) $C_{r.m.s}$ C) $\sqrt{2}\, C_{r.m.s}$ D) $2\, C_{r.m.s}$

Answer: A. $\frac{1}{\sqrt{2}} C_{r.m.s}$

7. **Which of the following is the ratio of root mean square speed of oxygen O_2 and hydrogen H_2 at same temperature?**
A) 1 : 2 B) 2 : 1 C) 1 : 4 D) 4 : 1

Answer: C. 1 : 4
(Since; M of H_2 is 2, O_2 is 32)

8. **Density of gas is 5 kg/m³ at a pressure of 6×10^5 Pa. Which of the following is root mean square velocity of gas molecules?**
A) 600 m/s B) 400 m/s C) 300 m/s D) 180 m/s

Answer: A) 600 m/s
Use formula:
$$c_{rms} = \sqrt{\frac{3\,P}{\rho}} = \sqrt{\frac{3 \times 6\times10^5}{5}} = 600 \text{ m/s}$$

9. **The average kinetic energy of gas molecules is:**
A) directly proportional to pressure of gas B) inversely proportional to volume of gas
C) inversely proportional to absolute temperature D) directly proportional to absolute temperature

Answer: D. Directly proportional to the absolute temperature of gas

10. **The pressure is exerted by the gas on walls of container because its molecules:**
A) loses kinetic energy B) stick to the walls
C) On collision with the walls, there is a change in momentum
D) On collision with the walls, gas molecules exert no force on wall

Answer: C. On collision with the walls, there is a change in momentum

11. **The rms speed of the molecules of enclosed gas is $C_{r.m.s.}$ Which of the following will be rms speed of gas molecules, if pressure is doubled keeping the temperature same?**
A) $\frac{1}{2}\,C_{r.m.s}$ B) $C_{r.m.s}$ C) $2\,C_{r.m.s}$ D) $4\,C_{r.m.s}$

Answer: B. $C_{r.m.s}$
(At constant temperature, , so if T is unchanged, remains same)

12. **A neutron star has a super high __________.**
A) density B) output of light C) input of neutrons D) output of x-rays

Answer: A. Density

13. Which of the following is the electrical resistance of superconductor below critical temperature?

A) finite B) large C) zero D) infinity

Answer: C. Zero

14. What is the process by which a Bose-Einstein condensate is formed?

A) fusion B) fission C) Decomposition

D) cooling to extremely low temperature

Answer: D. Cooling to extremely low temperature

✍️Short Questions:

1. **Mention the different ways of increasing the number of molecular collisions per unit time in a gas.**

Ans: There are many ways to increase number of molecular collisions per unit time in a gas:

- Increase pressure (by decreasing volume)
- Increase temperature
- Increase number of gas molecules
- Use smaller volume container

2. **By reducing the volume of a gas at constant temperature, the pressure of the gas increases. Explain it on the basis of kinetic theory.**

Ans: Volume reduction at constant temperature (Kinetic theory):
According to kinetic theory, when volume of gas is reduced keeping temperature constant, pressure increases because molecules collide more frequently with the walls due to reduced space, increasing force per unit area.

3. **What do you meant by the root mean square speed of molecules of a gas? Is the root mean square speed the same as average speed?**

Ans: According to the definition of root mean square speed; "It is the square root of the average of the squares of molecular speeds."
No, it is not equal to the average speed.
As,

$V_{r.m.s} = \sqrt{< v >^2}$, i.e. $v_{ave} < v_{r.m.s}$

4. **Why is temperature below absolute zero not possible?**

Ans: Because at absolute zero, molecular motion stops. You cannot have less motion than zero, so temperatures below 0 K are not physically meaningful.

5. Estimate the average energy of helium atom at the temperature on the surface of sun (6000 K).

Ans: The average energy can be calculated by using; $E = \frac{3}{2} k T$

$$E = \frac{3}{2}(1.38 \times 10^{-23} \times 6000)$$

$$E = 1.24 \times 10^{-19} \text{ J}$$

6. Show that the ratio of the root mean square speed of molecules of two different gases at a certain temperature is equal to the square root of the inverse of their masses.

Ans: As we knew that;

$V_{r.m.s} = \sqrt{\frac{3kT}{m}}$ so, $V_{r.m.s,\,1} = \sqrt{\frac{3kT}{m_1}}$ and $V_{r.m.s,\,2} = \sqrt{\frac{3kT}{m_2}}$

then, $$\frac{v_{rms,\ 1}}{v_{rms,\ 2}} = \sqrt{\frac{m_2}{m_1}}$$

So it is proved from above relation that the ratio of the root mean square speed of molecules of two different gases at a certain temperature is equal to the square root of the inverse of their masses.

7. Differentiate between the formation of white dwarfs and neutron stars.

Ans:

White dwarfs	**Neutron stars**
1. Composed of electrons and nuclei.	1. Composed mostly of neutrons.
2. Comparatively less denser.	2. Comparatively much denser.
3. Supported by electron degeneracy pressure.	3. Supported by neutron degeneracy pressure.

8. Why do gases at low temperature and high pressure show large deviation from ideal behavior?

Ans: At low temperature & high pressure gases show non-ideal behavior. It is due to the reason that at low T and high P, intermolecular forces and volume of gas particles become significant therefore, assumptions of ideal gas law fails.

9. What distinguishes degenerate matter from regular matter?

Ans: Degenerate matter resists compression due to quantum pressure (e.g. electron/neutron degeneracy), unlike normal matter governed by thermal pressure.

10. Show that the temperature of ideal gas is directly proportional to the average translational kinetic energy of gas molecules.

Ans: Proof of temperature ∝ average kinetic energy:

From kinetic theory of gases:

$$K.E = \frac{3}{2} k T$$

Since 3, 2 and k are constants, so $K.E \propto T$

Numerical problems

1. **The mass of helium atom is 6.64 × 10^{-27} kg. Calculate the root mean square speed of helium atoms in a gas at a temperature of 15 ℃.**

Given data:

$m = 6.64 \times 10^{-27}$ kg

$T = 15\ ℃ = 15 + 273 = 288$ K

$k_B = 1.38 \times 10^{-23}$ J / K

To find: $v_{rms} = ?$

Sol: $$v_{rms} = \sqrt{\frac{3\,k_B\,T}{m}}$$

$$v_{rms} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 288}{6.64 \times 10^{-27}}}$$

$$\mathbf{v_{rms} = 1339\ m/s = 1.34 \times 10^3\ m/s}$$

2. **At which temperature will the root mean square velocity of the oxygen molecules become equal to the escape velocity of earth (11.2 km/s). (mass of one molecule of oxygen is 5.3 × 10^{-26} kg and Boltzmann constant k = 1.38 × 10^{-23} J / K).**

Given data:

$v_{esc} = 11.2$ km/s $= 11200$ m/s

$m = 5.3 \times 10^{-26}$ kg

$k_B = 1.38 \times 10^{-23}$ J / K

To find: $T = ?$

Sol: $$v_{rms} = \sqrt{\frac{3\,k_B\,T}{m}}$$

By rearranging, we get;

$$T = \frac{V_{rms}^2\ m}{3\,k_B}$$

$$T = \frac{11200^2 \times 5.3 \times 10^{-26}}{3 \times 1.38 \times 10^{-23}}$$

$$\mathbf{T = 1.6 \times 10^5\ K}$$

3. The mass of molecule of a gas is 6.4×10^{-27} kg. Calculate the root mean square speed of gas molecules and kinetic energy per molecule at temperature 400 K.

Given data:

$m = 6.4 \times 10^{-27}$ kg

$T = 400$ K

$k_B = 1.38 \times 10^{-23}$ J / K

To find: $v_{rms} = ?$

K.E = ?

Sol: $$\mathbf{v_{rms} = \sqrt{\frac{3\,k_B\,T}{m}}}$$

$$v_{rms} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 400}{6.4 \times 10^{-27}}}$$

$$\mathbf{v_{rms} = 1.6 \times 10^{3}\ m/s}$$

$$\mathbf{K.E = \frac{1}{2}\,m\,v^2}$$

$$K.E = \frac{1}{2} \times 6.4 \times 10^{-27} \times (1.6 \times 10^{3})^2$$

$$\mathbf{K.E = 8.3 \times 10^{-21}\ J}$$

4. At which temperature the root mean square speed of gas molecules becomes double than its speed at 27 °C. (Pressure of gas is kept constant)

Given data:

$T_1 = 27\ ^\circ C = 27 + 273 = 300$ K

$v_2 = 2\,v_1$

To find: $T_2 = ?$

Sol: $$\mathbf{\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}}}$$

$$2 = \sqrt{\frac{T_2}{300}}$$

Taking square and rearranging

$$T_2 = 4 \times 300$$

$$\mathbf{T_2 = 1200\ K = 927\ ^\circ C}$$

5. **Determine the root mean square speed of argon atoms ay temperature 40 ℃. The molar mass of argon is 39.95 g / mol.**

Given data:

$T = 40\ ℃ = 40 + 273 = 313\ K$

$M = 39.95\ g / mol = 0.03995\ kg / mol$

$R = 8.314\ J / mol\ K$

To find: $v_{rms} = ?$

Sol: $\mathbf{v_{rms}} = \sqrt{\dfrac{\mathbf{3\ \mathit{R}\ T}}{\mathbf{M}}}$

$v_{rms} = \sqrt{\dfrac{3 \times 8.314 \times 313}{0.03995}}$

$\mathbf{v_{rms} = 442\ m/s = 4.42 \times 10^2\ m/s}$

6. **Calculate the number of gas molecules in a cubic meter of gas at standard temperature and pressure (STP).**

Given data:

$V = 1.0\ m^3$

$P = 1.01 \times 10^5\ Pa$

$T = 273.15\ K$

$N_A = 6.022 \times 10^{23}$ molecules / mol

$R = 8.314\ J / mol\ K$

To find: $N = ?$

Sol: $\mathbf{n\ R\ T = P\ V}$

$\dfrac{N}{N_A} = \dfrac{P\ V}{R\ T}$

$\mathbf{N} = \dfrac{\mathbf{P\ V\ N_A}}{\mathbf{R\ T}}$

$N = \dfrac{1.01 \times 10^5 \times 1 \times 6.022 \times 10^{23}}{8.314 \times 273.15}$

$\mathbf{N = 2.676 \times 10^{25}}$ **molecules**

7. A vessel 'A' contains hydrogen and another vessel 'B' whose volume is twice of vessel 'A' contains same amount of oxygen at the same temperature. Find (i) the ratio of root mean square speeds of hydrogen and oxygen gases, (ii) the ratio of pressure of gases in vessels A and B. (Molecular mass of hydrogen and oxygen are 2 and 32 respectively).

Given data:

$M_H = 2$ g / mol

$M_O = 32$ g / mol

$V_B = 2\ V_A$

To find: $\frac{v_H}{v_O} = ?$

$\frac{P_H}{P_O} = ?$

Sol: **(i)** As we knew that;

$$\boldsymbol{\frac{v_H}{v_O} = \sqrt{\frac{M_O}{M_H}}}$$

$$\frac{v_H}{v_O} = \sqrt{\frac{32}{2}}$$

$$\boldsymbol{\frac{v_H}{v_O} = \frac{4}{1}}$$

(ii) According to ideal gas equation

$P\ V = n\ R\ T$ so, $P = n\ R\ T / V$

By rearranging, we get;

$$\boldsymbol{\frac{P_H}{P_O} = \frac{n_H\ V_O}{n_O\ V_H}}$$

Here, $n_H = m / 2$ and $n_O = m / 32$ (masses are same) $(n = m / M)$

And if; $V_H = V$ then $V_O = 2\ V$

So, $$\frac{P_H}{P_O} = \frac{32 \times 2\ V}{2 \times V}$$

$$\boldsymbol{\frac{P_H}{P_O} = \frac{32}{1}}$$

Chapter # 17 (Exercise)

Multiple Choice Questions

Encircle the Correct option.

1) Which of the following statements is true regarding the acceleration of the particle executing simple harmonic motion?

A. zero at the mean position B. maximum at the mean position

C. zero at the extreme position D. constant

Explanation:

Since acceleration is directly related to the force (F = ma, where m is mass), a zero force results in zero acceleration.

2) If your heart rate is 150 beats per minute during strenuous exercise, what is the time per beat in seconds?

A. 150 B. 2.5 C.0.4 D. 0.0067

Solution:

time / beats = 60s / 150 = 0.4s / beat

3) Which of the following relationship between the acceleration 'a' and the displacement 'x' of a particle involves SHM?

A. $a = 0.7x$ B. $a = -200x^2$ C. $a = -10x$ D. $a = 100x^3$

Explanation: In simple harmonic motion, acceleration is directly proportion to the displacement from mean position ($a \propto -x$).

4) A mass-spring system undergoes simple harmonic motion has amplitude A. When the kinetic energy of the object equals twice the potential energy stored in the spring, what is the position 'x' of the object?

A. A B. A/3 C. $A/\sqrt{3}$ D. 0

Solution:

Given,

$$K.E = 2P.E$$

$$K/2 \ (A^2 - x^2) = 2 \ (1/2) \ kx^2$$

$$A^2 - x^2 = 2x^2$$

$$A^2 = 3x^2$$

$$x = A / \sqrt{3}$$

5) Suppose we replace the spring in a simple harmonic oscillator with a stronger spring, having twice the spring constant. What is the ratio of the new period of oscillation to the original period?

A. 1/2 B. $1/\sqrt{2}$ C. 1 D. $\sqrt{2}$

Solution:

$$\text{new period / initial period} = T / T_o = (2\pi \sqrt{m/2k}) / (2\pi \sqrt{m/k})$$

$$T / T_o = 1 / \sqrt{2}$$

6) A pinball machine uses a spring that is compressed 4.0 cm to launch a ball. If the spring constant is 13 N/m, what is the force on the ball at the moment the spring is released?

A. 52N B. 0.52 N C. 0.52 Nm D. 5.2 Nm

Solution:

Given,

$x = 4\text{cm} = 0.04$ m

$k = 13$ N/m

By Hook's law

$F = kx$

$F = (0.04)(13) = 0.52$ N

7) A particle is executing simple harmonic motion with period T. At time t =0 it is at the equilibrium point. At which time is it furthest from the equilibrium point?

A. 0.50 T B. 0.70 T C. 0.25 T D.1.4 T

Explanation:

In simple harmonic motion, a particle oscillates between two extreme points, passing through the equilibrium point in the middle. At time t=0, the particle is at the equilibrium point. The particle then moves away from the equilibrium point, reaches its maximum displacement (furthest point), then returns to the equilibrium point, continues to the other extreme point and then back to the equilibrium point to complete one full cycle.

When t = T/4:

It takes one-quarter of the period (T/4) for the particle to reach its maximum displacement from the equilibrium point for the first time.

When t = 3T/4:

It takes three-quarters of the period (3T/4) for the particle to reach the maximum displacement in the opposite direction (i.e., the other extreme).

8) The acceleration of a body executing simple harmonic motion leads the velocity by what phase?

A. 0 rad | B. π/8 rad | C. π/4 rad | D. π/2 rad

Explanation:

In simple harmonic motion (SHM), the acceleration leads the velocity by a phase of π/2 or 90 degrees. This means that when the velocity is zero, the acceleration is at its maximum, and when the velocity is at its maximum, the acceleration is zero.

The velocity of an object in SHM is described by a cosine function,

$$\textbf{velocity} = v = x_0\omega\cos(\omega t + \varphi)$$

The acceleration of an object in SHM is described by a negative sine function,

$$\textbf{acceleration} = a = -x_0\omega^2\sin(\omega t + \varphi) \text{ or } a = -\omega^2 x$$

The cosine function (velocity) is shifted by π/2 (90 degrees) compared to the sine function (acceleration). That's why the acceleration leads the velocity by π/2.

9) A simple pendulum has a period of 2.5 s. What is its period if its length is made four times larger?

A. 0.625 s | B. 1.25 s | C. 2.5 s | D. 5 s

Solution:

$$T / T_o = (2\pi \sqrt{4L/g}) / (2\pi \sqrt{L/g})$$

$$T / T_o = 2$$

$$T = 2T_o = 2(2.5) = 5 \text{ s}$$

10) What is the frequency of a pendulum that swings at the rate of 45 cycles per minute?

A. 0.75 Hz B. 1.3 Hz C. 2700 Hz D. 60 Hz

Solution:

Frequency = f = No. of beats / time = 45/60 = 0.75 Hz

11) A block at the end of a horizontal spring is pulled from equilibrium at x =0 to x = A, and then released. Through what total distance does it travel in one full cycle of its motion?

A. A/2 B. A C. 2A D. 4A

Explanation:

In one full cycle of its motion, the block will travel a total distance of 4A.

- **Initial Displacement:** The block is pulled from equilibrium at x=0 to x=A.
- **First Half Cycle:** When released, the block moves from x=A back to x=0 (distance A).
- **Second Half Cycle:** The block continues to x=-A (distance A).
- **Third Half Cycle:** The block moves from x=-A back to x=0 (distance A).
- **Fourth Half Cycle:** The block moves from x=0 back to x=A (distance A). **Therefore, the total distance traveled is A + A + A + A = 4A.**

12) A particle is vibrating simple harmonically with an acceleration of 16 cm s^{-2} when it is at a distance of 4cm from the mean position. Its time period is:

A. 1s B. 2.572 s C. 3.142 s D. 6.028 s

Solution:

Given, $a = 0.16\ m/s^2$

$x = 0.04$ m

Formula, $a = (2\pi / T)^2 x$

$0.16 = (2\pi / T)^2 (0.04)$

$(2\pi / T)^2 = 4$

$2\pi / T = 2$

T = 3.142s

Short Questions

1) If we halve the length of a simple pendulum to its original length, what is the alteration in the period of this pendulum? What is its new frequency?

Explanation:

The period (T) of a simple pendulum is given by the formula:

$$\mathbf{T = 2\pi\sqrt{L/g}}$$

where L is the length of the pendulum and g is the acceleration due to gravity.

If the length is halved (L' = L/2), the new period (T') can be calculated as:

$T' = 2\pi\sqrt{(L'/g)} = 2\pi\sqrt{(L/2g)} = 2\pi\sqrt{(L/g)} * \sqrt{(1/2)} = T / \sqrt{2}$.

Therefore, the new period is decreased by a factor of √2.

Frequency (f) is the inverse of the period (f = 1/T). So, if the period is reduced by a factor of √2, **the frequency is increased by a factor of √2.**

2) If the amplitude of vibration of a body executing SHM is doubled, what will happen to the maximum kinetic energy?

Explanation:

The total energy (E) of a system in SHM is given by the equation:

$$\mathbf{E = (1/2)\ kx_o^2} \text{ --------- (i)}$$

where 'm' is the mass, 'ω' is the angular frequency, and 'x_o' is the amplitude.

The maximum kinetic energy occurs when the particle passes through the equilibrium position, and its value is equal to the total energy:

$$K.E_{max} = E.$$

If the amplitude (A) is doubled, the new amplitude becomes 2A. Substituting this into the energy equation, we get:

$K.E_{max} = (1/2)\ k\ (2x_o)^2 = 4\ \{(1/2)\ kx_o^2\} = 4E.$

Conclusion:
The new total energy (and therefore the maximum kinetic energy) is **four times** the original energy.

3) When marching soldiers are about to cross a bridge, they break steps. Why?

Explanation:

When a structure is subjected to vibrations at its natural frequency, it can experience a phenomenon called resonance. Resonance causes the structure to vibrate with a much larger amplitude than it normally would. **When soldiers march in step, their footsteps create a rhythmic force with a specific frequency.** If this frequency happens to match the natural frequency of the bridge, the bridge can start to resonate.

In the case of a bridge, resonance can cause it to vibrate violently, potentially leading to structural damage or even collapse. **By breaking step, soldiers introduce a lack of synchronization in their footsteps, disrupting the rhythmic force and preventing the bridge from resonating.**

This practice, also known as **"route step,"** has been adopted by many militaries as a safety precaution when crossing bridges.

4) Suppose that a driving force has half frequency as compared to the frequency of an oscillator. Will it produce resonance? Similarly, if the driving frequency is twice the frequency of the oscillator, will it produce resonance?

Explanation:

Resonance occurs when the driving frequency equals the integral multiple of natural frequency of the oscillator. At this condition, the amplitude of oscillation becomes maximum.

Cases:

1. Driving frequency is half the natural frequency

$$f_{drive} = (1/2)\, f_o$$

- The driving force is **slower** than the system's natural oscillation.
- The driving frequency is not equal to the integral multiple of natural frequency of the oscillator.
- **No resonance** will occur.

2. Driving frequency is twice the natural frequency

$$f_{drive} = 2\, f_o$$

- The driving force is **faster** than the natural oscillation.
- The driving frequency is equal to the integral multiple of natural frequency of the oscillator.
- **Resonance** will occur here.

Conclusion:

- **Resonance only occurs when**:

$$f_{drive} = nf_o \qquad \text{Where 'n' is integer.}$$

5) Pendulum clocks are made to run at the correct rate by adjusting the pendulum's length. Suppose you move from one city to another where the acceleration due to gravity is slightly greater, taking your pendulum clock with you. Will you have to lengthen or shorten the pendulum to keep the correct time, other factors are remaining constant? Explain your answer.

Explanation:

If you move to a city where the acceleration due to **gravity is slightly greater**, you will need to **shorten the pendulum** to keep the clock running at the correct time.

Reason:

The time period T of a simple pendulum is given by the formula:

$$T=2\pi \sqrt{L/g}$$

Where:

- T is the period (time for one complete swing),
- L is the length of the pendulum,
- g is the acceleration due to gravity.

From the formula, if **'g' increases** (as in your new location), and length 'L' stays the same, then new time period **'T' becomes smaller**. This means the clock **ticks faster**, running ahead of time. To bring time period 'T' back to its original value (i.e., make the clock tick at the correct rate), you must reduce length 'L' so that the increase in 'g' is balanced out.

Conclusion: You must **shorten the pendulum** to compensate for the greater gravity.

6) Two mass-spring systems vibrate with simple harmonic motion. If the spring constants are equal and the mass of one system is twice that of the other, which system has a greater period?

Explanation:

The period T of a mass-spring system undergoing simple harmonic motion is:

$$T=2\pi\sqrt{m/k}$$

Where:

- T is the period,
- m is the mass,
- k is the spring constant.

Given,

Both systems have the **same spring constant** ‘k’. One system has mass ‘m’ and the other system has mass ‘2m’.

For mass m:

$T_1 = 2\pi\sqrt{m/k}$

For mass 2m:

$T_2 = 2\pi\sqrt{2m/k} = \sqrt{2}\ \{2\pi\sqrt{m/k}\} = \sqrt{2}\ T_1$

Conclusion:

- The system with **twice the mass** has a period that is **$\sqrt{2} \approx 1.41$** times **greater** than the lighter one.
- **Therefore, the system with the larger mass has the greater period.**

7) Give some applications in which resonance plays an important role.

Explanation:

1. Musical Instruments: Instruments like guitars, violins, and pianos rely on resonance to amplify the sound produced by vibrating strings or reeds. The instrument's body is designed to resonate at specific frequencies, enhancing the desired notes.

2. Radio and Television Tuning: When you tune a radio or television, you're adjusting the resonant frequency of an electrical circuit to match the frequency of the desired broadcast signal. This allows the receiver to select and amplify that specific signal while rejecting others.

3. Microwave Ovens: Microwave ovens use electromagnetic resonance to heat food. They generate microwaves that are absorbed by water molecules in the food, causing them to vibrate and generate heat.

4. Medical Imaging (MRI): Magnetic Resonance Imaging (MRI) uses nuclear magnetic resonance to create detailed images of the body's internal structures. The technique exploits the resonant properties of atomic nuclei in a strong magnetic field to differentiate between different tissues.

5. Tuning circuits in communication systems: Resonant circuits are used in various communication systems to filter and select specific frequencies, enabling efficient signal transmission and reception.

8) A simple pendulum is set into vibrations and left untouched, eventually stops, why?

Explanation:

A pendulum eventually stops swinging due to **energy loss caused by friction and air resistance**. As the pendulum swings, it converts potential energy to kinetic energy and back again. However, this energy is not conserved due to factors like air resistance, which slows down the pendulum and converts some of its kinetic energy into heat. Additionally, friction at the pendulum's pivot point further contributes to energy loss. Over time, these losses **reduce the amplitude** of the pendulum's swing until it eventually comes to a stop.

9) Under what condition(s) the motion of a simple pendulum be simple harmonic motion?

Explanation:

A simple pendulum exhibits simple harmonic motion (SHM) when the **angle of displacement from the vertical is small**. Specifically, for angles less than approximately **15 degrees**, the restoring force is nearly directly proportional to the displacement, a key characteristic of SHM. For larger angles, the restoring force deviates significantly from this proportionality, and the motion is no longer considered simple harmonic.

10) At what position is the velocity of a particle executing simple harmonic motion a) maximum b) minimum?

In simple harmonic motion (SHM), the **velocity of a particle is maximum at the mean position and minimum (zero) at the extreme positions**.

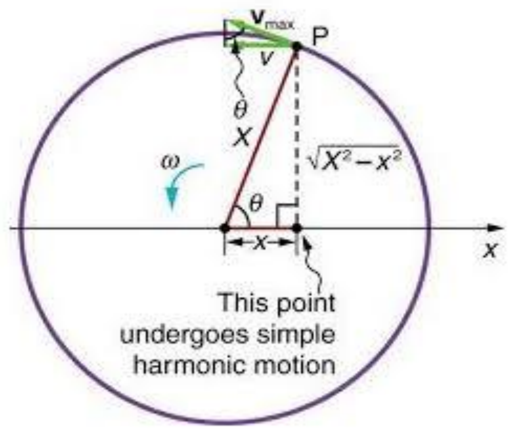
Explanation:

Mean Position:

At the mean position, the particle is at its equilibrium point, where the restoring force is zero. This allows the particle to reach its **maximum speed** as it passes through this point.

Extreme Positions:
At the extreme positions, the particle momentarily comes to rest before changing direction. This means the **velocity is zero** at these points.

11) Show that the motion of projection of a body revolving in a circle describes S.H.M.



The projection of a body moving in uniform circular motion onto a diameter of the circle will perform Simple Harmonic Motion (SHM). This can be demonstrated by showing that the displacement of the projection satisfies the equation of SHM.

- Imagine a point 'P' moving around a circle at a constant speed ω.
- The position of the point can be described using an angle (θ) that increases linearly with time (**$\theta = \omega t$,** where ω is the angular velocity).
- Consider a line (diameter) passing through the center of the circle.
- The projection of the point 'P' onto this diameter is the shadow it casts on the line.
- The acceleration of point 'P' is centripetal which is directed towards the center of circle.
- When the point 'P' moves along the circular path, its projection oscillates on the diameter of circle.
- The component of acceleration of point 'P' in the direction of diameter is given as:

$$a = -x_o \, \omega^2 \cos\theta \quad \text{------- (i)}$$

- At any time 't', the displacement 'x' of the projection from the center of the circle can be found using trigonometry.

$$x = x_o \cos\theta \quad \text{------------ (ii)}$$

From equation (i) and (ii)

$$a = -\omega^2 x$$

$$a \propto -x$$

This equation describes the SHM. Hence we can conclude that when a body moves in a circle, its projection undergoes SHM on the diameter of the circle.

12) sketch displacement-time graphs to illustrate light, critical and heavy damping.

13) Justify the importance of critical damping in a car suspension system.

Explanation:

Critical damping in a car suspension system is important because it provides the **optimal balance** between comfort and handling. It allows the suspension to **absorb shocks** from bumps and uneven surfaces without excessive bouncing or oscillation, ensuring a smooth and stable ride while maintaining good road contact for effective handling.

14) Differentiate free and forced oscillations.

Free Oscillations:

Definition: Occur when a system oscillates without any external force acting on it.

Driving Force: The system oscillates due to its inherent properties (like mass and stiffness) and initial displacement.

Frequency: Oscillates at its natural frequency, which is determined by the system's physical characteristics.

Examples: A plucked guitar string vibrating, a pendulum swinging freely after an initial push.

Forced Oscillations:

Definition: Occur when an external periodic force drives the system to oscillate.

Driving Force: The system oscillates at the frequency of the applied external force.

Frequency: The frequency of oscillation is determined by the external force, not the system's natural frequency.

Examples: Pushing a child on a swing, a vibrating tuning fork held against a tabletop.

15) How the time period of a simple pendulum changes if mass of its bob is doubled?

Explanation:

Simple Pendulum:

The time period (T) of a simple pendulum is determined by the formula:

$$T = 2\pi\sqrt{L/g}$$

where L is the length of the pendulum and g is the acceleration due to gravity.

As you can see, the mass (m) of the bob is not a factor in the equation. Therefore, doubling the mass has **no effect** on the time period.

Numerical Problems

1) The amplitude of the motion of a mass attached to a spring is 2.48 m, while maximum speed of its mass is 4.36 m/s. What is the period of the motion?

Data:

$$\text{Amplitude} = x_0 = 2.48\ m$$

$$\text{Maximum speed} = V_0 = 4.36\ ms^{-1}$$

$$\text{Time period} = T = ?$$

Solution:

$$V_0 = x_0\omega$$

$$\omega = \frac{V_0}{x_0}$$

$$\omega = \frac{4.36}{2.48} = 1.7581\ rad/s$$

$$T = \frac{2\pi}{\omega}$$

$$T = \frac{2(3.14)}{1.7581} = 3.573\ s$$

2) A particle moves, whose displacement as a function of time is: x =3.0 cos(2t), where distance is measured in meter and time in second.

a) Calculate the amplitude, the frequency, the angular frequency and the period of this particle?

Data:

Displacement = $x = 3\cos 2t$ ……….(1)

Amplitude = $x_0 = ?$

Frequency = $f = ?$

Angular frequency = $\omega = ?$

Time period = $T = ?$

Solution:

The general form of SHM is

$x = x_0 \cos \omega t$ ……. (2)

From (1) and (2)

$$x_0 = 3\ m$$

$$\omega = 2\ rad/s$$

$$\omega = 2\pi f$$

$$f = \frac{\omega}{2\pi}$$

$$f = \frac{2}{2(3.14)}$$

$$f = 0.31\ Hz$$

$$T = \frac{1}{f} = \frac{1}{0.318} = 3.14\ s$$

b) Calculate the time at which the particle reaches the midpoint (i.e., x =0) and the turning point?

Data:

Time required to reach the midpoint = $t_1 = ?$

Time required to reach the turning point = $t_2 = ?$

Solution:

Time required to reach the midpoint:

$$t_1 = \frac{T}{4}$$

$$t_1 = \frac{3.14}{4} = 0.78\ s$$

Time required to reach the turning point:

$$t_2 = \frac{T}{2}$$

$$t_1 = \frac{3.14}{2} = 1.57\ s$$

3) A particle executes simple harmonic motion, that moves back and forth along x-axis between points -0.20 m and +0.20 m. The period of the motion is 1.2 s. At the time t =0, the particle is at +0.20 m and its velocity is zero.

a) What is the frequency of the motion and the angular frequency?

Data:

Time period = $T = 1.2\ s$

Amplitude= $x_0 = 0.2\ m$

Frequency = $f = ?$

Angular frequency = $\omega = ?$

Solution:

$$f = \frac{1}{T}$$

$$f = \frac{1}{1.2} = 0.83\ Hz$$

$$\omega = 2\pi f$$

$$\omega = 2(3.14)(0.83)$$

$$\omega = 5.2\ rad/s$$

b) What is the amplitude of the motion?

Given,

Amplitude = $x_0 = 2.0\ m$

c) At what time will the particle reach the point x =0? At what time will the particle reach the point x =0.10 m?

Data:

Time required to reach the midpoint ($x = 0\ m$) = $t_1 = ?$

Time required to reach the point ($x = 0.10\ m$) = $t_2 = ?$

Solution:

Time required to reach the midpoint ($\boldsymbol{x = 0\ m}$)

$$t_1 = \frac{T}{4}$$

$$t_1 = \frac{1.2}{4} = 0.30\ s$$

Time required to reach the point ($\boldsymbol{x = 0.10\ m}$)

$$x = x_0 \cos \omega t_2$$

$$0.1 = (0.2) \cos \omega t_2$$

$$\cos \omega t_2 = \frac{0.1}{0.2}$$

$$\cos \omega t_2 = 0.5$$

$$\omega t_2 = \cos^{-1}(0.5)$$

$$\omega t_2 = \frac{\pi}{3}$$

$$t_2 = \frac{\pi}{3\omega}$$

$$t_2 = \frac{3.14}{3(5.2)}$$

$$t_2 = 0.20\ s$$

d) What is the speed of the particle when it is at x =0? What is the speed of the particle when it reaches the point x =0.10 m?

Data:

Speed of the particle (at $x = 0$) = $V_{max} = ?$

Speed of the particle (at $x = 0.10\ m$) = $V_{min} = ?$

Solution:

At $x = 0$

$$V_{max} = \omega x_0$$

$$V_{max} = (5.2)(0.20)$$

$$V_{max} = 1.04\ ms^{-1}$$

At $x = 1.0\ m$

$$V_{min} = \omega\sqrt{x_0^2 - x^2}$$

$$V_{min} = (5.2)\sqrt{(0.20)^2 - (0.10)^2}$$

$$V_{min} = (5.2)\sqrt{0.173}$$

$$V_{min} = 0.90\ ms^{-1}$$

4) A mass of 8.0 kg is attached to a spring and oscillates with amplitude of 0.25 m and has a frequency of 0.60 Hz. What is the energy of the motion?

Data:

Mass = $m = 8.0\ kg$

Amplitude = $x_0 = 0.25\ m$

Frequency = $f = 0.60\ Hz$

Energy of motion = $E = ?$

Solution:

$$\omega = 2\pi f$$

$$\omega = 2(3.14)(0.60)$$

$$\omega = 3.77\ rad/s$$

We know that $\omega^2 = \frac{k}{m}$

$$k = m\omega^2$$

$$k = (8.0)(3.77)^2$$

$$k = 113.7\ Nm^{-1}$$

$$Total\ Energy = E = \frac{1}{2}kx_0^2$$

$$E = \frac{1}{2}(113.7)(0.25)^2$$

$$E = 3.6\ J$$

5) Calculate the period and frequency of a 3.5 m long pendulum at the following locations:

a) at Karachi, where g_1 =9.832 ms^{-2}.

Data:

Value of '$\boldsymbol{g}$' at Karachi = $g_1 = 9.832\ ms^{-2}$

Length of pendulum =$L = 3.5\ m$

Period= T_1 =?

$$\text{Frequency} = f_1 = ?$$

Solution:

$$T_1 = 2\pi\sqrt{\frac{L}{g_1}}$$

$$T_1 = 2(3.14)\sqrt{\frac{3.5}{9.832}}$$

$$T_1 = 3.747\ s$$

$$f_1 = \frac{1}{T_1}$$

$$f_1 = \frac{1}{3.747} = 0.2669\ Hz$$

b) at K-2, where g_2 =9.782 ms^{-2}.

Data:

$$\text{Value of '}\boldsymbol{g}\text{' at K-2} = g_2 = 9.782\ ms^{-2}$$

$$\text{Length of pendulum} = L = 3.5\ m$$

$$\text{Period} = T_2 = ?$$

$$\text{Frequency} = f_2 = ?$$

Solution:

$$T_2 = 2\pi\sqrt{\frac{L}{g_2}}$$

$$T_2 = 2(3.14)\sqrt{\frac{3.5}{9.782}}$$

$$T_2 = 3.756\ s$$

$$f_2 = \frac{1}{T_2}$$

$$f_2 = \frac{1}{3.756} = 0.2662\ Hz$$

6) In a car engine, a piston executes SHM with amplitude of 0.41 m. The engine is running at angular frequency of 2400 rpm (251 rad/s). What is the maximum speed of the piston?

Data:

Amplitude = $x_0 = 0.14\ m$

Angular frequency = $\omega = 251\ rad/s$

Maximum speed = $V_0 = ?$

Solution:

$$V_0 = \omega x_0$$

$$V_0 = (251)(0.41)$$

$$V_0 = 103\ ms^{-1}$$

7) A ball connected to a spring executes SHM. At t =0, its displacement is 0.50 m and its acceleration is -0.72 ms^{-2}. The phase constant for its motion is 0.84 rad. What is the ball's displacement at t =3.4 s?

Data:

At time = $t_1 = 0$

Displacement = $x_1 = 0.50\ m$

Acceleration = $a = -0.72\ ms^{-2}$

$$\text{Phase constant} = \phi = 0.84\, rad$$

At time = $t_2 = 3.4\, s$

$$\text{Displacement} = x_2 = ?$$

Solution:

The displacement in SHM is given by

$$x_1 = x_0 \cos(\omega t_1 + \phi)$$

At $t_1 = 0$, this becomes

$$0.50 = x_0 \cos(0 + 0.84)$$

$$0.50 = x_0(0.99)$$

$$x_0 = \frac{0.50}{0.99}$$

$$x_0 = 0.50\, m$$

Now we find $'\omega'$ by using

$$a = -\omega^2 x_1$$

$$\omega^2 = -\frac{a}{x_1}$$

$$\omega^2 = -(\frac{-0.72}{0.50})$$

$$\omega^2 = 1.44$$

$$\omega = \sqrt{1.44}$$

$$\omega = 1.2\, rad/s$$

At time $t_2 = 3.4\, s$

$$x_2 = x_0 \cos(\omega t_2 + \phi)$$

$$x_2 = (0.50) \cos\big((1.2)(3.4) + 0.84\big)$$

$$x_2 = (0.50) \cos(4.92)$$

$$x_2 = (0.50)(0.21)$$

$$x_2 = 0.15\ m$$

Assignments

Assignment # 17.1

An object with mass 500g is suspended from a spring. The spring is stretched by 9.8cm. Calculate the spring constant.

Data:

$$\text{Suspended mass} = m = 500\ g = 0.5\ kg$$

$$\text{Displacement} = x = 9.8\ cm = 0.098\ m$$

$$\text{Spring constant} = k = ?$$

Solution:

$$F = kx$$

$$k = \frac{F}{x}$$

$$k = \frac{mg}{x} \qquad (F = w = mg)$$

$$k = \frac{(0.5)(9.8)}{0.098}$$

$$k = 50\ Nm^{-1}$$

Assignment # 17.2

Time period of a mass attached at the end of a spring is 0.40 s. Find out the magnitude of acceleration when the displacement is 4 cm.

Data:

$$\text{Time period} = T = 0.42\ s$$

$$\text{Acceleration} = a = ?$$

$$\text{Displacement} = x = 4\ cm = 0.04\ m$$

Solution:

$$\omega = \frac{2\pi}{T}$$

$$\omega = \frac{2(3.14)}{0.42}$$

$$\omega = 14.95\ rad/s$$

$$a = \omega^2 x$$

$$a = (14.95)^2(0.04)$$

$$a = 8.940\ ms^{-2}$$

Assignment # 17.3

Find the time periods of a simple pendulum with length 1m, placed on earth and on moon. The value of g on the surface of moon is 1/6th of its value on earth.

Data:

Length of pendulum = $L = 1m$

Value of 'g' on the surface of earth = $g_e = 9.8\ ms^{-2}$

Value of 'g' on the surface of moon = $g_m = \frac{g_e}{6} = \frac{9.8}{6} = 1.63\ ms^{-2}$

Time period on the surface of earth = $T_e = ?$

Time period on the surface of moon = $T_m = ?$

Solution:

$$T_e = 2\pi\sqrt{\frac{L}{g_e}}$$

$$T_e = 2(3.14)\sqrt{\frac{1}{9.8}}$$

$$T_e = 2.0\ s$$

$$T_m = 2\pi\sqrt{\frac{L}{g_m}}$$

$$T_m = 2(3.14)\sqrt{\frac{1}{1.6}}$$

$$T_m = 4.96\ s$$

Assignment # 17.4

Find the amplitude, frequency and time period of an object oscillating at the end of a spring, if the equation for its position at any instant t is given by x = 0.25 cos (π/8)t. Also find the displacement of the object after 2.0 s.

Data:

$$x = 0.25\cos\left(\frac{\pi}{8}t_1\right) \ldots\ldots\ldots\ldots(i)$$

Displacement after 2.0 s = $x = ?$

Amplitude = $x_0 = ?$

Frequency = $f = ?$

Time period = $T = ?$

Solution:

The displacement in SHM is given by

$$x = x_0 \cos \omega t_1 \ldots\ldots\ldots(ii)$$

From (i) and (ii)

$$x_0 = 0.25\ m$$

$$\omega = \frac{\pi}{8}$$

$$\omega = 0.3925\ rad/s$$

$$T = \frac{2\pi}{\omega}$$

$$T = \frac{2(3.14)}{0.3925}$$

$$T = 165 \text{ s}$$

$$f = \frac{1}{T}$$

$$f = \frac{1}{16}$$

$$f = 0.0625\ Hz$$

After $t_2 = 2.0\ s$

$$x = x_0 \cos \omega t_2$$

$$x = (0.25) \cos(0.3925 \times 2.0)$$

$$x = (0.25) \cos(0.785)$$

$$x = (0.25)(0.99)$$

$$x = 0.2475\ m$$

Physics Part-II
Chapter No.18 Exercise Solution

Encircle the correct option

1. **Rainbows are formed due to:**
   A. Reflection of sunlight by water droplets
   B. Refraction of sunlight by water droplets
   C. Interference of sunlight by water droplets
   D. Diffraction of sunlight by water droplets
   Explanation:
   Rainbows are created due to a combination of **refraction**, **internal reflection**, and **interference** of sunlight inside raindrops. The interference leads to the separation of white light into its constituent colors
2. **In the double-slit experiment, a pattern of bright and dark bands is observed. This pattern is evidence of:**
   A. Reflection of light
   B. Refraction of light
   C. Wave nature of light
   D. All of above
   Explanation:
   The bright and dark fringes in Young's double-slit experiment result from **constructive and destructive interference**, which is a property of waves.
3. **A laser passes through two slits separated by 0.005 mm. The third bright fringe is observed at 18° on the screen. What is the wavelength?**
   A. 51.1 nm
   B. 77.3 nm
   C. 515 nm
   D. 773 nm
   Given:
   - $d = 0.005$ mm $= 5 \times 10^{-6}$ m
   - $\theta = 18°$
   - $m = 3$
   - Use: $\mathbf{d \sin \theta = m \lambda}$

   Solution:
   $\lambda = (d * \sin\theta) / m = (5 \times 10^{-6} \sin(18°)) / 3 \approx 515$ nm

4. **What is the width of a slit if 610 nm light forms the first diffraction minimum at 30°?**
   A. 0.863 µm
   B. 0.704 µm
   C. 0.610 µm
   D. 1.22 µm
   Given:
   - $\lambda = 610$ nm $= 610 \times 10^{-9}$ m
   - [$\theta = 30°$, $m = 1$
   - Use: $\mathbf{d \sin \theta = m \lambda}$

   Solution:
   $d = \lambda / \sin\theta = 610 \times 10^{-9}$ m $/ \sin(30°) = 1.220 \times 10^{-6}$ m $= 1.22$ µm

5. **Two slits separated by 3500 nm. Light with wavelength 500 nm. m-th minimum at 30°. What is m?**
   A. 0
   B. 1
   C. 2
   D. 3
   Given:

d = 3500 nm, λ = 500 nm, θ = 30°

Use: **d sin θ = (m+ 1/2) λ**

Solution:

m = (d * sin θ) / λ – 1/2 = (3500 × sin (30°)) / 500 - 1/2≈ 3

6. **What is a diffraction grating?**
   A. A Single slit that produce diffraction pattern
   B. A double slit that produces interference pattern
   C. A periodic arrangement of slits or lines that produces a diffraction pattern
   D. A random arrangement of slits or lines that produces a diffraction pattern

   Explanation:

   A diffraction grating has **equally spaced slits or grooves** that diffract light into well-defined directions depending on the wavelength

7. **Bending of light when passing through a narrow slit is called:**
   A. Reflection
   B. Refraction
   C. Diffraction
   D. Dispersion

   Explanation:

   When light bends around obstacles or spreads after passing through a slit, it's called **diffraction**.

8. **Why does a diffraction grating separate white light into colors?**
   A. It absorbs certain colors.
   B. It reflects different colors at different angles
   C. It diffracts different colors at different angles
   D. It refracts different colors at different angles

   Explanation:

   Each wavelength (color) of light diffracts at a different angle due to the equation **d sin θ = m λ**, so a grating spatially separates them.

9. **If the slits are brought closer, how does the spacing of the bands change?**
   A. The bands would be closer together
   B. The bands would be spread farther apart
   C. The bands would remain stationary
   D. The bands would fade and eventually disappear

   Explanation:

   Fringe spacing **Δ x = λ D/d**, so if slit separation **d increases**, **Δ x decreases** — bands get closer.

10. **What is diffraction of light?**
    A. The bending of light around an obstacle
    B. The reflection of light from surface
    C. The refraction of light through medium
    D. The interference of light waves

    Explanation:

    Diffraction occurs when light bends around the edges of an obstacle or opening.

11. **Why doesn't a needle tip give a sharp image?**
    A. Polarization
    B. interference
    C. Diffraction
    D. Refraction

    Explanation:

    The interference of light from different points of the tip causes image blurring.

12. **What pattern is seen on the screen in double-slit experiment?**
    A. A bright central maximum with alternating dark and bright fringes
    B. A dark central minimum with alternating bright and dark fringes
    C. A uniform intensity pattern
    D. A random pattern

Explanation:

Interference causes alternating **constructive (bright)** and **destructive (dark)** fringes.

13. Wavelength of light falling on slits separated by 2.0 μm, third-order maximum at 60°?

A. 667 nm B. 471 nm C. 33 nm D. 577 nm

Use: d sin θ = m λ

d = 2 μm = 2×10^{-6} m, θ = 60°, m = 3

λ = (2×10^{-6} **sin (60°)) / 3 ≈ 577 nm**

14. Longest wavelength of light passing through slit of 1.20 μm for first-order minimum?

A. 1.04 μm B. 0.849 μm C. 0.600 μm D. 2.40 μm

Use: a sin θ = m λ

a = 1.20 μm, θ = 90°, m=1

λ = 1.20 μm * sin (90°) = 1.20 μm (All options are Incorrect)

15. What is distance between grating lines for 760 nm light producing 2nd order max at 60°?

A. 2.28×10^4 nm B. 3.29×10^2 nm C. 2.53×10^{-5} nm D. 1.76×10^3 nm

Use: d sin θ = m λ

m = 2, θ = 60, λ = 760 nm

d = (m λ)/sin θ = ($2 \times 760 \times 10^{-9}$) / sin (60°) ≈ 1.76×10^3 nm

Conceptual Questions

1. How is an interference pattern formed by a diffraction grating different from the pattern formed by a double slit?

Ans. A diffraction grating produces a sharper and brighter interference pattern than a double slit. The maxima (bright fringes) are narrower and more intense, while the minima (dark fringes) are more pronounced. This is because a diffraction grating has many slits, leading to more constructive and destructive interference patterns, concentrating the light at specific angles

- A **double-slit** interference pattern has bright and dark fringes that are **relatively broad and less sharp**.
- A **diffraction grating** has a large number of slits, producing **much sharper and brighter principal maxima** with **dark areas in between**.
- The interference pattern from a grating is more **intense, narrow**, and **well-defined** due to the constructive interference from many slits.

2. A beam of light always spreads out. Why can a beam not be produced with parallel rays to prevent spreading?

Ans. A beam of light always spreads out due to the wave nature of light and the phenomenon of diffraction.

- According to **Huygens' principle**, every point on a wavefront acts as a secondary source. As a result, light tends to spread.
- Even a highly collimated (parallel) beam, like a laser, undergoes **diffraction**, causing it to **diverge slowly over distance**.
- Thus, complete prevention of spreading is impossible due to the **wave nature** of light.

3. In the sunlight, the shadow of a building has fuzzy edges even if the building does not. Is this a refraction effect? Explain

Ans. The fuzzy edges of a building's shadow in sunlight are caused by diffraction, not refraction. This diffraction occurs as light waves bend around the building's edges, causing the shadow to have a blurred outline.

- No, this is **not a refraction** effect.
- The fuzzy edges are due to **diffraction of sunlight** at the edges of the building.
- This causes the **penumbra** (partial shadow) around the **umbra** (full shadow), making edges appear blurred.

4. A laser pointer emits a coherent beam of parallel light rays. Does the light from such a source spread out at all? Explain.

Ans.

- Yes, even laser beams **spread out** slightly due to **diffraction**.
- Although lasers are **highly collimated** and **coherent**, they are still subject to **wave effects**, and cannot maintain perfectly parallel rays over long distances.

5. A beam of light passes through a single slit to create a diffraction pattern. How will the spacing of the bands in the pattern change if the width of the slit is increased?

Ans. A beam of light passes through a single slit to create a diffraction pattern.

- The central maximum becomes **narrower** and **less spread out**.
- Increasing slit width **decreases diffraction**, so the **fringes move closer together**.
- This is because fringe width is **inversely proportional** to slit width

6. Describe a diffraction grating and the interference pattern it produces?

Ans.

- A **diffraction grating** is an optical device with many equally spaced parallel slits (typically thousands per cm).
- When light passes through it, it diffracts and produces **constructive interference** at specific angles.
- The resulting pattern has:
  - **Bright, sharp principal maxima** at specific orders (m = 1, 2, …).
  - **Dark regions** between maxima.
  - The pattern depends on **wavelength, grating spacing, and order of maxima**.

7. Suppose a monochromatic light falls on a diffraction grating. What happens to the interference pattern if the same light falls on a grating that has more lines per centimeter?

Ans.

- **More lines/cm** means **smaller slit separation (d)**.
- According to the grating equation $d \sin\theta = m\lambda$, $d = m\lambda \backslash \sin\theta$, for smaller d, the angle θ for each order **increases**.
- Hence, **maxima spread farther apart** and the **pattern becomes more resolved and sharper**.

8. What is the significance of the equation $d \sin\theta = m\lambda$, $d = m\lambda \backslash \sin\theta$ **in the context of:**

Ans.

(a) Diffraction gratings:

- It relates the **angle θ** of constructive interference to the order m, wavelength λ, and slit separation d.
- Shows that **only certain angles** satisfy the condition for maxima.

(b) Young's double-slit experiment:

- A similar principle applies: interference fringes are due to **path difference** between the two slits.
- Instead of angle, it is often used to calculate **fringe spacing** on a screen using geometry.

9. What is the effect of the following aspects of diffraction grating on the resulting interference pattern?

Ans.

(a) Number of slits:

- **More slits** produce **sharper, brighter, and more intense** principal maxima.
- Also increases the **contrast** between bright and dark regions.

(b) Width of the slits:

- **Narrower slits** allow for more **pronounced diffraction**, spreading the pattern more.
- Wider slits cause **less diffraction**, narrowing the pattern.

10. Describe the conditions necessary for sustained interference patterns to be observed in Young's double-slit experiment.

Ans.

- **(a) Coherent sources**: Light waves must have a **constant phase difference**.
- **Monochromatic light**: To avoid overlapping of patterns from different wavelengths.
- **Same polarization**: Interfering beams must be polarized in the same direction.
- **Equal or nearly equal intensity**: For clear, visible fringes.

Small slit separation and proper distance to the screen: To produce measurable fringe spacing.

Numerical

1. The light with wavelength (A) 633 nm is used at a distance of 2 m from the screen. The separation between the slits is 10 µm. Find the distance between adjacent maxima (fringe width) for the first (m = 1) and second (m = 2) order of interference?

Ans: Given data:

Wavelength= $\lambda = 633$ nm $= 633 \times 10^{-9}$ m
Distance to screen, D = 2 m
Slit separation, d = 10 µm $= 10 \times 10^{-6}$ m
Formula: Fringe width $y = (m * \lambda * D)/d$

Solution:

For m = 1: $y_1 = (1 \times 633 \times 10^{-9} \times 2) / (10 \times 10^{-6}) = 0.127$ m
For m = 2: $y_2 = (2 \times 633 \times 10^{-9} \times 2) / (10 \times 10^{-6}) = 0.253$ m
Distance between adjacent maxima = 0.126 m

Answer: 1st order = 0.127 m, 2nd order = 0.253 m apart from 1st

2- Find the distance from the central maximum to the third minimum on the screen, if the light of wavelength 400 nm is used. The distance between the slits and screen is 0.5 m and slit separation is 5 µm?

Ans: Given data:

λ = 400 nm = 400 x 10^{-9} m, D = 0.5 m, d = 5 **µ**m = 5 x 10^{-6} m

Formula: y = ((m + 0.5) * λ * D)/d,

for 3rd minimum: m = 2

y = ((2 + 0.5) x 400 x 10^{-9} x 0.5) / (5 x 10^{-6}) = 0.1 m

Answer: 0.1m

3- The distance between the slits and screen is 1m, fringe spacing on screen is 1 mm. Find the slit separation when light wavelength is 500 nm.

Ans: Given data:

D = 1 m, y = 1 mm = 1 x 10^{-3} m, λ = 500 nm = 500 x 10^{-9} m

Formula: d = (λ * D)/ y = (500 x 10^{-9} x 1)/ (1 x 10^{-3}) = 5x10^{-4}m

Answer: 5x10^{-4}m

4- Find the minimum angle for non-zero diffracted light, having slit spacing 2.0 µm with 400 nm light wavelength.

Ans: Given data: λ = 400 nm = 400 x 10^{-9} m, d = 2.0 m = 2 x 10^{-6} m

Formula: sin θ = λ / d = 400 x 10^{-9} / 2 x 10^{-6} = 0.2

θ = $\sin^{-}$ (0.2) = 11.54°

5- The deviation of second order diffracted image formed by an optical grating having 5000 lines per centimeter is 32°. Calculate the wavelength of light used?

Ans: Given data:

m = 2, θ = 32°, N_m = 5000 lines/cm = 5000 lines/cm×100 cm/1 m=500000 lines/m

grating spacing = d =1/N_m = 1/500000 m/ lines = 2 x 10^{-6} m

Formula: λ = (d x sin(θ))/m = (2 x 10^{-4} x sin 32°)/2

lambda (2 x 10^{-6} x 0.5299)/2 = 5.3 x 10^{-7} m

Answer: 5.3 x 10^{-7} m

Assignment # 01

light from He-Ne laser pass through the two-slit separated by 0.01 00 mm the third Bright Line on screen is formed at a angle of 10.95 degree relative to the incident beam. What is the wavelength of the light?

Given Data: d= 0.01 00x10^{-3} m = 1.0x10^{-5}, m = 3

Θ = 10.95°, λ=?

Formula: λ = (d x sin(θ))/m

= (1.0x10^{-5} x sin (10.95°)/3

=6.33x10^{-7} m

= 6.33x10^{-7}m

Assignment # 02

Visible light a wavelength 550nm falls on the single slit and produce your second diffraction minimum at an angle of 45° relative to the incident direction of light. what is the width of the slit?

Given Data: m = 2, d=?

$\Theta = 45^o$, $\lambda = 550nm = 5.50x10^{-7}m$

Formula: $d = m\,\lambda / \sin(\theta)$

d= $(2x5.50x10^{-7}m / \sin(10.95^o)$

$= 1.555x10^{-6}$ m

$\approx 1.56\mu m$

Encircle the correct option.

1. Which of the following is equivalent to **1.0 volt**?
A. Newton/second
B. Joule/second
C. **Joule/Coulomb**
D. Coulomb/Joule
2. The quantity **electric potential** is defined as the amount of:
A. Electric potential energy
B. Force acting upon a charge
C. **Potential energy per unit charge**
D. Force per unit charge
3. A negatively charged particle is placed in a uniform electric field directed from **South to North**. In which direction will the particle move after it is released?
A. East
B. South
C. North
D. North-West
4. What is the charge that appears on the plates of a **10 μF capacitor** if it is connected to a battery of **9 V**?
A. 90 pC
B. 90 mC
C. 90 kC
D. 90 μC
5. What is the voltage that should be applied to a **5 μF capacitor** to accumulate **1 μC** of charge on its plates?
A. 0.2 V
B. 0.2 mV
C. 0.2 kV
D. 0.2 μV
6. Capacitor is a device used to:
A. Store electrical energy
B. Vary the resistance
C. Store magnetic energy
D. Dissipate energy
7. What is the total capacitance when three capacitors, $C1$, $C2$, and $C3$, are connected in **parallel**?
A. $C2+C3C1$
B. $C1+C2+C3$
C. $C1+C3C2$
D. $C1+C2+C31$
8. If three capacitors of capacitances **1 μF**, **2 μF**, and **10 μF** are connected in parallel, then their equivalent capacitance will be:
A. 10 μF
B. **13 μF**
C. 15 μF
D. 20 μF

9. When capacitors are connected in parallel, the total capacitance is always ___ the individual capacitance values.
A. **Greater than**
B. Less than
C. Equal to
D. Cannot be determined

10. What is the capacitance of a capacitor?
    A. **The ratio of charge to electric potential difference**
    B. The ratio of electric potential difference to charge
    C. The product of charge and electric potential difference
    D. The ratio of electric field strength to charge density
11. What is the electric potential difference between two points?
    A. **The work done in moving a unit charge between the two points**
    B. The force exerted on a unit charge at one of the points
    C. The electric field strength between the two points
    D. The distance between the two points

12. A **220 Ω** resistor is in series with a **2.2 μF** capacitor. The time constant is:
    A. 48 μs
    B. **484 μs**
    C. 2.42 μs
    D. 24 μs
13. The formula for electrostatic potential is:
    A. Electrostatic potential = Work done × charge
    B. **Electrostatic potential = Work done / charge**
    C. Electrostatic potential = Work done + charge
    D. Electrostatic potential = Charge / Work done

1	C	V= $\frac{W}{q}$
2	C	V= $\frac{energy}{charge}$
3	B	South , F=qE 1. A negatively charged particle will experience a force in the opposite direction of the electric field. 2. Since the electric field is directed from South to North, the negatively charged particle will experience a force directed from North to South. 3. Therefore, the particle will move in the **South** direction
4	D	Q=cv Q=(10μF)×(9V) Q=90μC
5	A	V= $\frac{Q}{C}$ V= $\frac{1\mu C}{5\mu F}$ V=0.2v
6	A	Capacitor store electrical energy in the form of electric field
7	B	In parallel combination of capacitor equivalent capacitor is increase $C_e= C_1 +C_2+C_{3+}$................
8	B	$C_e= C_1 +C_2+C_3$ C_e=1μF+2μF+10μF
9	A	In parallel combination of capacitor equivalent capacitor is increase
10	A	C= $\frac{Q}{V}$
11	A	V= $\frac{Work}{charge}$
12	B	t=Rc , t=(220Ω)×(2.2μF)= 484μs
13	B	V= $\frac{Work}{charge}$

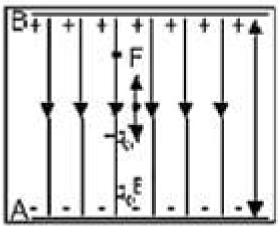
Short Questions

What is the relationship between electric potential and electric potential energy?
Both of them are closely related with each other.

Explanation:

- Let to plates A and B are oppositely charged. A positive test charge of very small magnitude and dimension is displaced from A to B.
- So the work is done in bringing it from A to B and it increases the electric potential energy of the charge.
- This work done per unit charged is called potential difference.
- So: $\Delta V = \frac{W_{AB}}{q_0}$

  $W_{AB} = \Delta U$
- $\Delta V = \frac{\Delta U}{q_0}$
- Hence change in potential energy per unit test charge is called potential difference.
- Electric potential energy is possessed by the charge whereas the potential difference is the property of associated with electric field.



2.If you wish to store a large amount of energy in a capacitor bank, would you connect capacitors in series or parallel? Explain.

a) To store a large amount of energy, capacitors should be connected **in parallel**.
This is because the total capacitance in parallel is the sum of individual capacitances:

$C_{total} = C_1 + C_2 + C_{3+}$................

Since energy stored in a capacitor is given by:

$E = \frac{1}{2} CV^2$

So, in parallel combination equivalent capacitance is increases and hence energy stored in a capacitor is increases.

b) When capacitors are connected in series their equivalent capacitance is decreases

$$C_s = \frac{C}{n}$$

Hence, energy is also decreasing.

3. **What are the units of:**

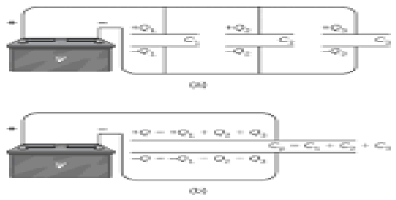
a) **Electric potential difference → Volt (V)**
b) **Electric potential energy → Joule (J)**
c) **Capacitance → Farad (F)**

a $\quad V = \frac{Work}{charge}$

b $\quad$ work=energy =U=potential difference ×Charge

c $\quad C = \frac{Q}{V}$

4. **What is the net amount of charge on a charged capacitor?**



The net charge on a charged capacitor is typically zero.

This is because a capacitor consists of two conductive plates, and when charged, one plate accumulates an equal amount of positive charge while the other accumulates an equal amount of negative charge. These equal and opposite charges cancel each other out, resulting in a net charge of zero for the entire capacitor.

5. **Write some applications of capacitors in real life.**

- Used in power supplies to smooth output.
- In camera flashes and defibrillators to store energy.
- In tuning circuits of radios and TVs.
- In timing circuits and filters.
- In touchscreens and sensors.

6. **Would you place the plates of a parallel-plate capacitor closer together or farther apart to increase their capacitance?**

To **increase capacitance**, the plates should be placed **closer together**

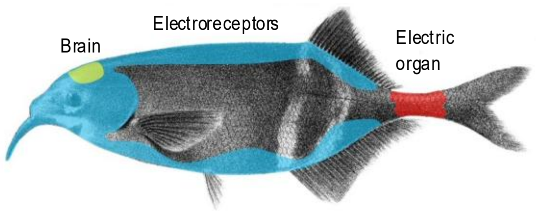
$$C = \frac{A\varepsilon_0\varepsilon r}{d}$$

The capacitance (C) of a parallel-plate capacitor is inversely proportional to the distance (d) between the plates, Therefore, decreasing the distance (d) between the plates will increase the capacitance (C)

7. **What is meant by electroreception?**

Electroreception is the ability of some animals (like sharks, rays, and certain fish) to detect electric fields produced by other animals or objects in their environment.

It is a sensory perception used mainly in **aquatic animals** like **sharks, rays, electric fish**, and some amphibians.



These animals have special sensory organs (e.g., **ampullae of Lorenzini** in sharks) that can detect weak electric fields generated by **other living organisms**, such as the muscle contractions or nerve impulses of prey.

Some species, like electric fish, can also generate electric fields and use the distortion of these fields to **navigate, communicate**, or locate objects—this is called **active electroreception**.

Animals that only detect electric fields (but do not generate them) use **passive electroreception**.

8. **If you were asked to design a capacitor in which small size and large capacitance were required, what would be the two most important factors in your design?**

$$C = \frac{A\varepsilon_0\varepsilon r}{d}$$

To design a small size capacitor with a high capacitance, three points are key:

a) use a material with high permittivity for the dielectric,

b) maximize the plate surface area for example, using plates with elaborate designs

c) minimize the distance between the plates.

9. **If a capacitor is fully charged and then left for discharging, how much charge will be left on the plates of the capacitor after time equal to one time constant?**

To determine how much charge remains on the plates of a discharging capacitor after one time constant, let's break it down step by step.

1.Discharging Equation for a Capacitor

The charge $Q(t)$ on a capacitor during discharging follows an exponential decay:

$Q(t)=Q_0e{-}\frac{t}{\tau}$

- Q_0 = Initial charge (when fully charged)
- τ = Time constant ($\tau=RC$, where R is resistance and C is capacitance)
- t = Time elapsed

2. Evaluating at $t=\tau$

Substitute $t=\tau$ into the equation:

$Q(\tau)=Q_0e{-}\frac{t}{\tau}=Q_0e{-}1$

3. Simplifying

Since $e{-}1\approx0.3679$, the remaining charge is:

$Q(\tau)\approx0.3679Q_0$

4. Conclusion

After **one time constant (**τ**)**, approximately **36.8% 0r 37%** of the initial charge remains on the capacitor plates.

36.8% of the initial charge

Numerical Problems

1. **A heart defibrillator delivers** 4×102 **J of energy by discharging a capacitor initially at** 1×104 **V. What is its capacitance?**

   $E=\frac{1}{2}CV^2$

   $C=\frac{2E}{V^2}$

   $C=\frac{2\times4\times10^2}{1\times10^8}$

   C= $8\times10-6$ F

   C=8 µF

   Answer: 8 µF

2. **Two capacitors of capacitance** $C1=6\mu F$ **and** $C2=3\mu F$ **are connected in series. Calculate the equivalent capacitance.**

   $C1=6\mu F$
   $C2=3\mu F$
   $\frac{1}{Ceq}=\frac{1}{C1}+\frac{1}{C2}+\frac{1}{C3}$………………
   For two unequal capacitors

   $Ceq=\frac{C1C2}{C1+C2}$

   $Ceq=\frac{6\mu F\times3\mu F}{6\mu F+3\mu F}$

   $Ceq=\frac{18\mu F}{9\mu F}$

   $Ceq=2$ µF

   Answer: 2 µF

3. **A 2200 µF capacitor is charged up with a 1.5 V cell. Calculate the charge and energy stored in the capacitor.**

   $Q=CV$

   $Q=2200\times10^{-6}$

   $\times1.5$

   Q=3.3 mC

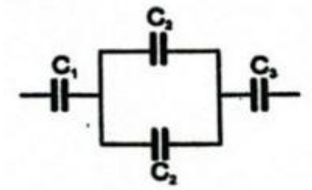
   $E=\frac{1}{2}CV^2$

   $E=\frac{1}{2}(2200\times10^{-6})(1.5)^2$

   E= 0.00248 J or 3.3mC

   Answer: 3.3 mC, 0.00248 J

4. **Find the equivalent capacitance for the following circuit if:**



$C1$=1pF, $C2$=0.5pF, $C3$=1pF

Both C_2 both capacitors are in parallel so

$C_2^{/}= C_2 + C_2$

$C_2^{/}=$ 0.5 pF + 0.5pF

$C_2^{/}=$ 1 pF

Now C_1, $C_2^{/}$, and C_3 are in series

$\frac{1}{Ceq}=\frac{1}{C1}+\frac{1}{C2/}+\frac{1}{C3}$………………

$\frac{1}{Ceq}=\frac{1}{1pF}+\frac{1}{1pF}+\frac{1}{1pF}$………………

$\frac{1}{Ceq}=\frac{1+1+1}{1}$pF

$\frac{1}{Ceq}=\frac{3}{1}$pF

$Ceq=\frac{1}{3}$pF

5. **Suppose electrons in a TV tube are accelerated through a potential difference of 2.0×104V from the heated cathode toward the screen (anode), 25.0 cm away.**

(a) At what speed would the electrons impact the phosphors on the screen?

Assume they accelerate from rest and ignore relativistic effects.

$\frac{1}{2}mv^2=qV$

$v=\sqrt{2qV/m}$

For electron:
$q=1.6\times10^{-19}$C

$m=9.11\times10^{-31}$kg

$v=\sqrt{2(1.6\times10^{-19})\ 2\times104/(9.11\times10^{-31})}$

$v = 8.38\times10^{7}$m/s

Answer: 8.38×10^{7}m/s

(b) What is the magnitude of the electric field, if it is assumed constant?

$$E = \frac{V}{d}$$

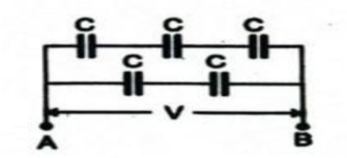
$$E = \frac{2\times10^{4}}{25\times10^{-2}}$$

$$E = 8.0\times10^{4} V/m$$

Answer: 8.0×10^{4} V/m

6. **A network of five capacitors of capacitance *C* is connected to a 100 V supply, as shown in the figure. Determine the equivalent capacitance of the network.**

Upper three capacitors are in series



$$\frac{1}{Ceq} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C}\ldots\ldots\ldots\ldots\ldots\ldots$$

For identical capacitor

$$C_1 = \frac{C}{n}$$

Where n is no of capacitors

$$C1 = \frac{C}{3}$$

Lower two capacitors are in series so

$$C_2 = \frac{C}{2}$$

Now C_1 and C_2 are in parallel so

$$C_e = C_1 + C_2$$

$$C_e = \frac{C}{3} + \frac{C}{2}$$

$$C_e = \frac{2+3}{6} C$$

$$C_e = \frac{5}{6} C$$

Multiple Choice Questions

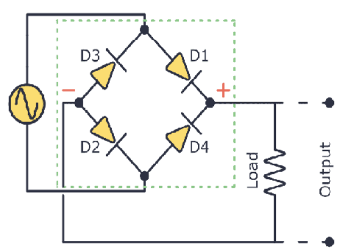
1) A full wave bridge rectifier consists of

A. no diode

B. one diode

C. Two diodes

D. four diodes



2) Unit of reactance is

A. henry

B. ohms

C. volt

D. ampere

(Opposition due to current in inductor or capacitor called reactance it's like resistance)

3) The unit of self-inductance, henry (H), is equal to

A. A $s^{-1}V^{-1}$

B. VAs^{-1}

C. V$s^{-1}A^{-1}$

D. VsA^{-1}

Solution

Formula for self-inductance is ε_L = -L$\frac{\Delta I}{\Delta t}$

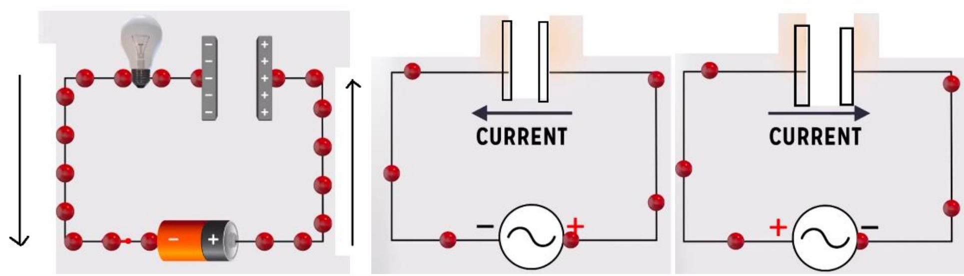
4) A capacitor is perfectly insulator for

A. direct current

B. alternating current

C. direct as well as alternating current

D. neither for direct current nor for alternating current



$X_c = \frac{1}{\omega c} = \frac{1}{2\pi f C}$

For dc f = 0 so $X_c = \infty$

I = $\frac{V}{X_c} = \frac{V}{\infty}$ = 0

5) The peak value of alternating current is 5$\sqrt{2}$ A. The mean square value of current will be

A. 5 A

B. 2.5 A

C. 5$\sqrt{2}$ A

D. $5^2\ A^2$

solution

$I_\circ$ = 5$\sqrt{2}$ A

I_{rms} = $\frac{I_\circ}{\sqrt{2}}$

I_{rms} = $\frac{5\sqrt{2}\text{ A}}{\sqrt{2}}$ =5A

mean square value of current = $(RMS)^2$

I^2mean= 5^2A^2

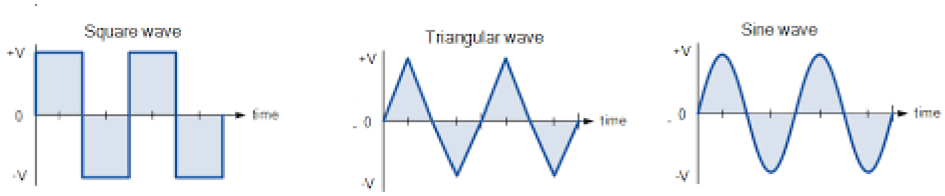
6) In AC system we generate sine wave form because

A. It can be easily draw

B. It produces least disturbance in electrical circuits

C. It is nature standard

D. Other waves cannot be produced easily.



7) An alternating voltage is given by 20sin(157t). The frequency of alternating voltage is

A. 50 Hz

B. 25 Hz

C. 100 Hz

D. 75 Hz

solution

V = $V_{\circ} \sin \omega t$

$V_{\circ}$ = 20

ω = 157

As we know **ω**= 2**π**f

$f = \frac{\omega}{2\pi} = \frac{157}{2 \times 3.14} = 25 \text{ HZ}$

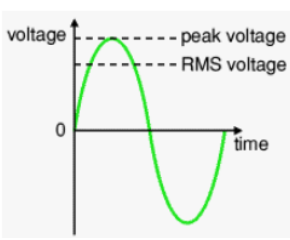
8) Peak value of an alternating quantity (voltage or current) can be found if we know it's

A. phase

B. r.m.s value

C. frequency

D. both (a) & (b)



$I_{rms} = \frac{I_{\circ}}{\sqrt{2}}$

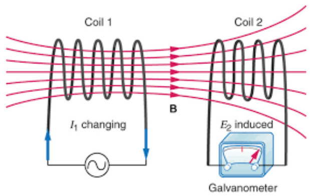
Short Question

1) Define (a) mutual-induction (b) self-induction.

Mutual Induction

When current changes in one coil and emf induced in second coil called mutual induction.

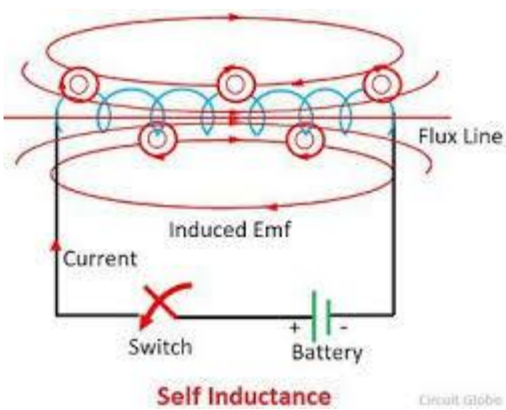
ε_S = -M$\frac{\Delta I_P}{\Delta t}$



Self-Induction

When current changes in one coil and emf induced in itself called self-induction.

ε_P = -L$\frac{\Delta I_P}{\Delta t}$



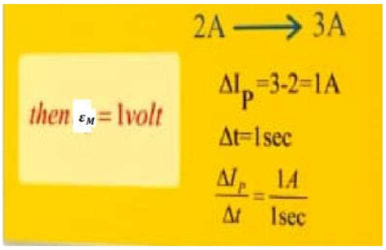
2) Does the SI unit used for mutual-inductance and self-inductance are same? Explain briefly.

Yes, both have the same SI unit: Henry (H).

Because both involve the induced EMF due to change in current.

$\boldsymbol{\varepsilon_L}$ **= L**$\boldsymbol{\frac{\Delta I}{\Delta t}}$

L = $\boldsymbol{\frac{\varepsilon_L}{\frac{\Delta I}{\Delta t}} = \frac{\varepsilon_L \Delta t}{\Delta I}}$**=** $\boldsymbol{\frac{VS}{A}}$

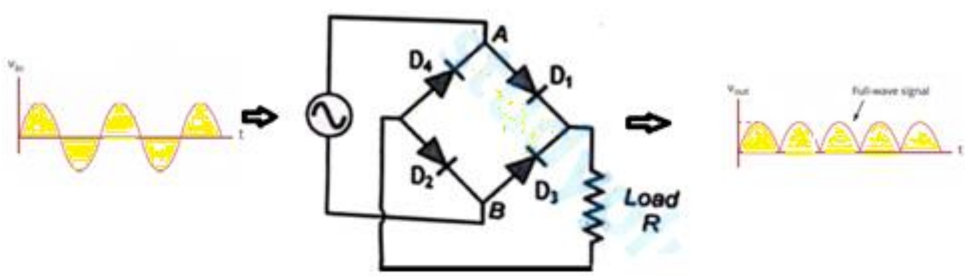


ε_M = M$\frac{\Delta I}{\Delta t}$

M= $\frac{\varepsilon_M}{\frac{\Delta I}{\Delta t}} = \frac{\varepsilon_M \Delta t}{\Delta I} = \frac{VS}{A}$

3) Draw the circuit for a half wave rectifier and full wave rectifier.

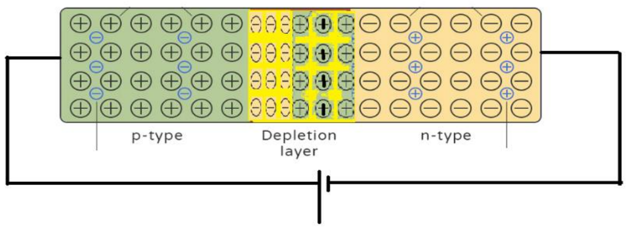
Half-wave rectifier circuit.

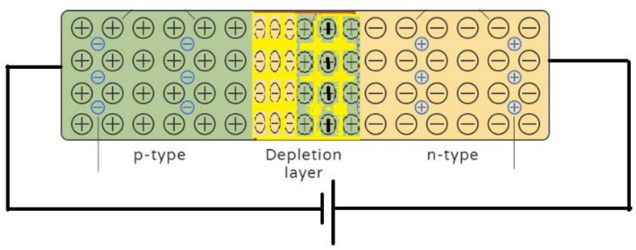


Full wave rectification

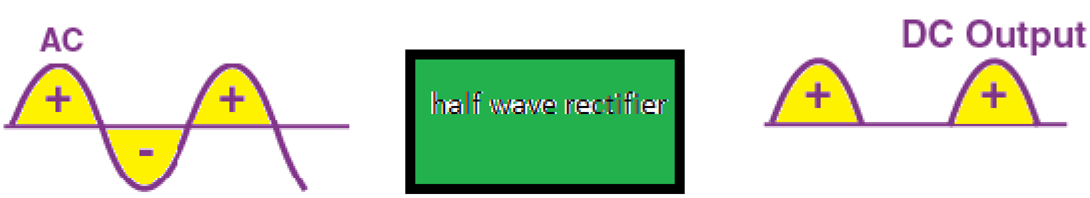
4) What is the use of a single diode for the half-wave rectification of an alternating current?

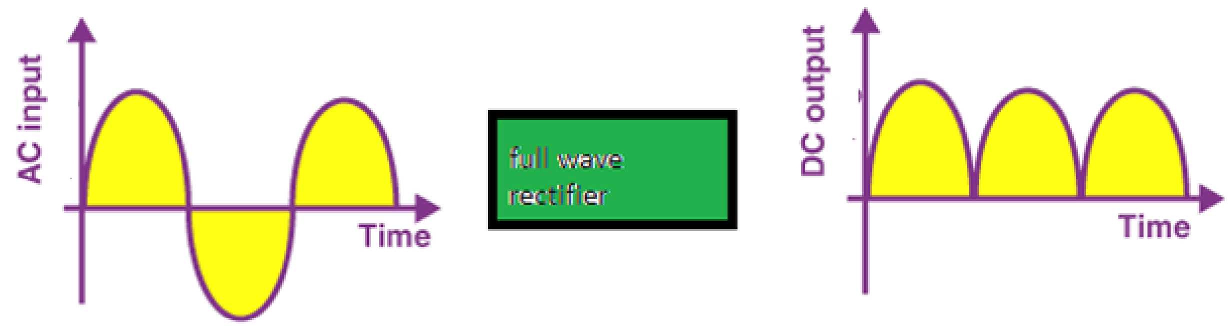
In forward bias of diode, it acts as a closed switch while in reverse bias it acts as an open switch. Diode allows only one directional current that's why it can be used as a rectifier. A single diode allows only positive or only negative half cycle of ac.





5) Distinguish graphically between half-wave and full-wave rectification.

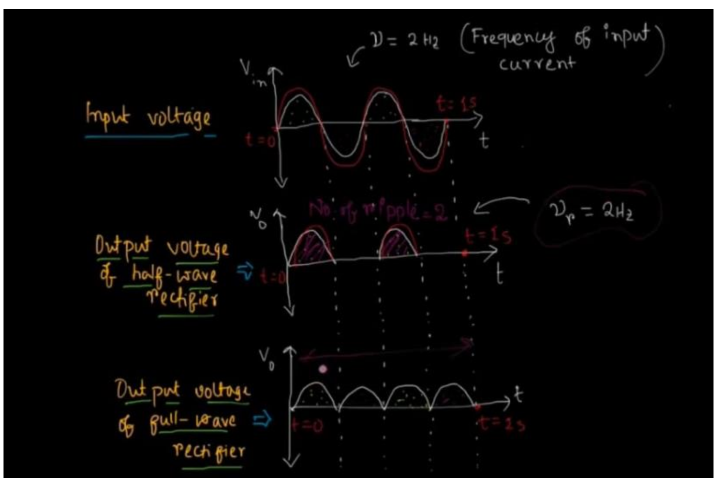




6) Is the frequency content of the output of a half wave rectifier and full wave rectifier the same? Explain briefly.

No the frequency content is different.

The half-wave rectifier's output frequency is the same as the input, while the full-wave rectifier's output frequency is double the input frequency this is because the full wave rectifier utilizes both half of AC.



7) In half wave rectifier, the half of the signal is blocked after the rectification. Why?

Because during positive half of ac cycle diode acts as a forward bias (on switch) and during negative half of ac cycle it acts as reverse bias (off switch) so half of ac signal is blocked.

8) Distinguish between root-mean-square (r.m.s.) and peak values for a sinusoidal alternating current.

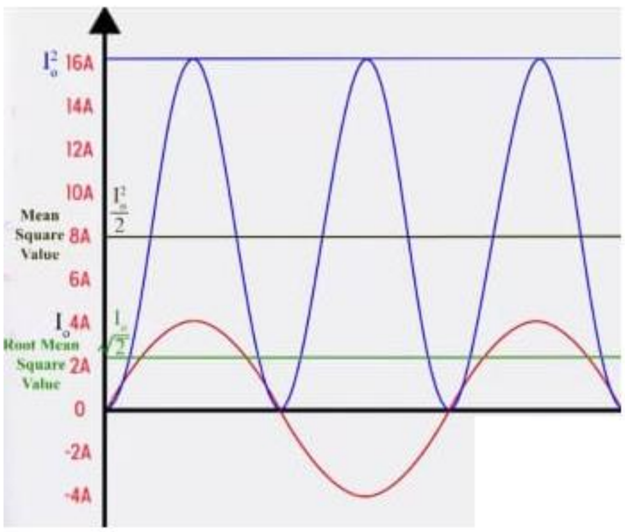
Peak value

The maximum value of AC during a cycle is called peak value.

Root mean square value (RMS)

Effective value of ac current in a circuit is called rms value.it is

$$I_{rms} = \frac{I_\circ}{\sqrt{2}}$$



9) What is impedance? How is it related to resistance, reactance, and frequency? Also find its SI unit?

Impedance (Z) is the total opposition to flow of AC current in a circuit.

Formula Z $= \sqrt{R^2 + X^2}$

Reactance x depends upon frequency

Inductive reactance = X_L= 2πfL

Capacitive reactance = $X_C = \frac{1}{2\pi f C}$

SI Unit Ohm (Ω)

10) What is the difference between reactance and impedance?

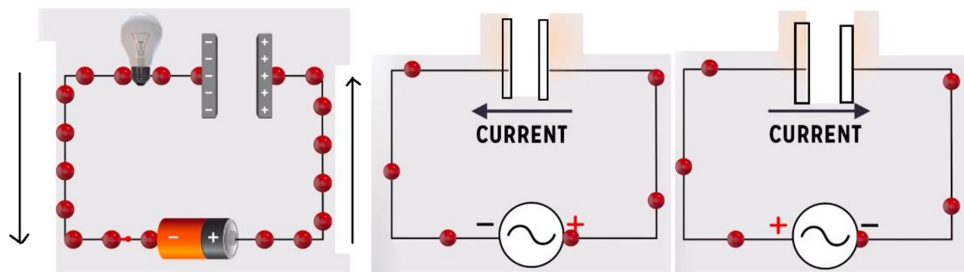
Reactance: Opposition is due to capacitor or inductor.

Impedance: Total opposition (resistance + reactance).

11) Why does a capacitor block DC but allow AC to pass through?

For DC, capacitor charges once and stops current.

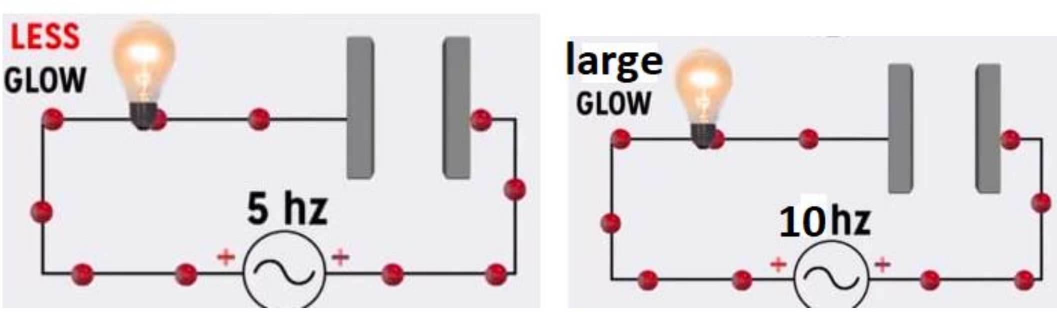
For AC, current changes direction, so capacitor charges and discharges continuously so its allow current flow.



12) How does the reactance of a capacitor change with an increase in frequency?

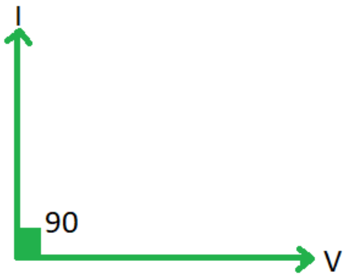
Capacitive reactance = $X_C = \frac{1}{2\pi f C}$

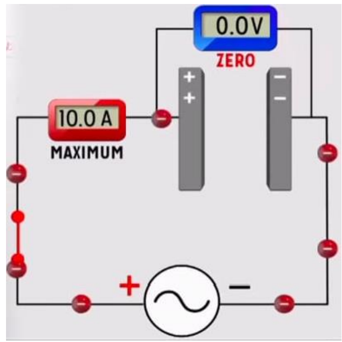
From above relation its clear reactance of a capacitor decreases with an increase in frequency.



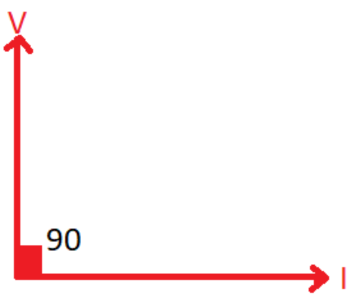
13) What is the phase difference between voltage and current in a (a) capacitor (b) Inductor?

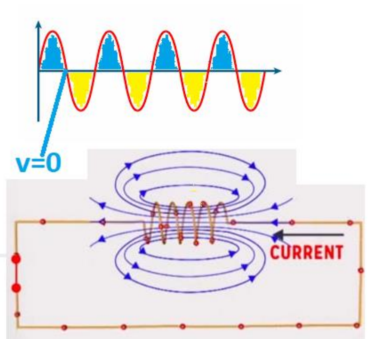
(a) capacitor: Current leads voltage by 90°





(b) inductor: voltage leads current by 90°





14) How does the capacitance of a capacitor affect the current through it in an AC circuit?

Higher capacitance = lower reactance, so more current flows.

Capacitive reactance = $X_C = \frac{1}{2\pi f C}$

Numerical Problems

1) What is the rms value of the voltage of an ac supply having peak voltage 300 V? (Answer: 212 V)

Given V_o = 300V

Find V_{rms} = ?

formula

$$V_{rms} = \frac{V_\circ}{\sqrt{2}}$$

$$V_{rms} = \frac{300}{\sqrt{2}}$$

$$V_{rms} = 212.13\text{V}$$

2) An inductor with an inductance of 100 µH passes a current of 10mA when its terminal voltage is 6.3 V. Calculate the frequency of A.C supply.

Voltage = 6.3 V

Current = 10 mA

Find = f =?

Formula

$$X_L = 2\pi fL \qquad \text{here } X_L = \frac{V}{I} = \frac{6.3V}{10mA} = 630\Omega$$

$$f = \frac{X_L}{2\pi L} = \frac{630}{2\times3.14\times100\times10^{-6}} = 1\times10^{6}\text{Hz}$$

3) A coil of pure inductance 318 mH is connected in series with a pure resistance of 75Ω. The voltage across resistor is 150 V and the frequency of power supply is 50 Hz. Calculate impedance of the circuit.

Given

L = 318 mH

f = 50 Hz

Find impedance = Z =?

Formula

Z = $\sqrt{R^2 + {X_L}^2}$ Here X_L **=** 2**π**f L = (2)(3.14)(50)(318) = 99.9Ω

Z = $\sqrt{(75)^2 + (99.9)^2}$

Z = 124.90Ω

4) A resistor of resistance 30Ω is connected in series with a capacitor of capacitance 79.5 µF across a power supply of 50 Hz and 100 V. Find impedance of the circuit.

Given

R = 30Ω

C= 79.5 µF

f= 50 Hz

find impedance = z =?

Formula

Z = $\sqrt{R^2 + {X_c}^2}$ Here X_C = $\frac{1}{2\pi f C}$ = $\frac{1}{2\times3.14\times50\times79.5}$ = 40Ω

Z = $\sqrt{(30)^2 + (40)^2}$ Z = 50 Ω

Exercise ch 21 Quantum mechanics

Multiple choice questions

1. Which of the following spectral region has the highest energy?
   a) infrared. b) violet. c) red d) blue
2. Which of the following statements is true about photon?
   a) A photon has zero mass and zero momentum
   b) A photon has finite mas and finite value of momentum
   c) A photon has zero mass and finite value of momentum
   d) A photon has finite mass and zero value of momentum
3. What happens to kinetic energy of emitted electrons when light is incident on metal surface?
   a) It varies with the frequency of light b) It varies with the light intensity
   c) It varies with the speed of light. d) It varies irregularly
4. A photoelectric cell is a device which
   a) convert light energy into electrical energy
   b) convert electricity into light energy
   c) stores light energy
   d) stores electricity
5. Which property does the Compton effect describe about photons?
   a) mass. b) momentum. c) wave speed. d) speed rates
6. What happens to a high energy photon after it strikes an electron ?
   a) decreases frequency. b) decreases wavelength
   c) increases energy. d) increases momentum
7. Energy of gamma photon having wavelength of $1A^0$ is:
   a)12.4×10^4eV b) 1.24×10^4eV. c) 12.4×10^4eV d) 12.4×10^4eV
   8. If uncertainty in the position of an electron is zero, the uncertainty in it's momentum will be
   a) less then h/4π. b) greater than h/4π. c) zero. d) infinite
9. What is the process by which a particle and it's antiparticle annihilate each other?
   a) pair production. b) pair annihilation. c) Nuclear fission. d) Nuclear fusion
10. Which of the following particle is produced during pair annihilation?
   a) photon. b) electron. d) proton. d) neutron

Short Questions

1. Prove that energy and momentum of photon are directly proportional to each other.

   Energy of a Photon

   $$E = hf = \frac{hc}{\lambda}$$

Momentum of a Photon

$$p = \frac{h}{\lambda}$$

Dividing E by p:

$$\frac{E}{p} = c$$

$E = pc$

Conclusion

The energy (E) of a photon is directly proportional to its momentum (p), with the speed of light (c) being the constant of proportionality.

2. Convert 800MeV into joules.

Conversion Factor

$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

Calculation

$1 \text{ MeV} = 10^{6} \text{ eV}$

$800 \text{ MeV} = 800 \times 10^{6} \text{eV}$

In joules:

$800 \text{ MeV} = 800 \times 10^{6} \times 1.602 \times 10^{-19} \text{ J}$

$= 800 \times 1.602 \times 10^{-13} \text{ J}$

$= 1.2816 \times 10^{-10} \text{J}$

The energy in joules is approximately 1.28×10^{-10}J.

3. Write the two phenomena to describe photon- electron interaction.

Two key phenomena that describe photon-electron interactions are:

1. Photoelectric Effect: The ejection of electrons from a material when photons of sufficient energy hit it.

2. Compton Effect: The scattering of photons by free electrons, resulting in a transfer of energy and momentum between the photon and the electron.

4. In the interpretation of photoelectric effect, how is it known that electron does not absorb more than one photon?

According to Einstein's explanation of the photoelectric effect. The energy of the photon ($E = hf$) is absorbed by a single electron. If the photon's energy is greater than the work function (Φ) of the material, the electron is emitted with a maximum kinetic energy given by:

$K.\ E_{max} = hf - \Phi$

Why an Electron Absorbs Only One Photon

The reason an electron absorbs only one photon is due to the following:

Energy Conservation: The energy and momentum conservation laws dictate that the energy transferred from a single photon to an electron is sufficient for emission if the photon's energy exceeds the work function.

Instantaneous Process: The absorption process is instantaneous, and the probability of absorbing multiple photons simultaneously is extremely low.

Experimental Evidence: The linear dependence of the maximum kinetic energy of emitted electrons on the frequency (not intensity) of light supports the single-photon absorption mechanism.

5. How you can determine the work function from a plot of the stopping potential versus the frequency of the incident radiation in the photoelectric effect experiment?can you determine the value of Planck's constant from this plot?

From a plot of stopping potential (V_0) versus frequency (f) of incident radiation:

Equation

$eV_0 = hf - \Phi$

Rearranging

$V_0 = (h/e)\ f - \Phi/e$

Plot Analysis

The slope of the line is h/e.

The y-intercept is $-\Phi/e$.

Determining Work Function

$\Phi = -e \times (\text{y-intercept})$

Determining Planck's Constant

$h = e \times \text{slope}$

By analyzing the slope and y-intercept of the V_0 vs. f plot, both Planck's constant (h) and the work function (Φ) can be determined.

6. Speculate how increasing the temperature of a photo electrode effects the outcomes of the photoelectric effect experiment.

Increasing the temperature of a photoelectrode can have several effects on the photoelectric effect experiment:

1. Thermionic Emission: Higher temperatures can lead to increased thermionic emission, where electrons are emitted due to thermal energy alone. This can increase the background current and potentially affect measurements.

2. Work Function Changes: Temperature changes can slightly alter the work function of the material, potentially affecting the threshold frequency and the kinetic energy of emitted electrons.

3. Increased Electron-Phonon Interactions: Higher temperatures can lead to increased lattice vibrations (phonons), which might affect the electron's ability to absorb photon energy and escape the material.

Experimental Implications

These effects might require consideration when interpreting results, especially at high temperatures or when precise measurements are crucial.

7. Which espects of the photoelectric effect cannot be explained by classical physics?

The following aspects of the photoelectric effect cannot be explained by classical physics:

1. Threshold Frequency: Classical physics predicts that electrons should be emitted regardless of frequency, as long as the intensity is high enough. However, the photoelectric effect shows a threshold frequency below which no electrons are emitted.

2. Instantaneous Emission: Classical physics suggests a time delay between light absorption and electron emission, but the photoelectric effect shows instantaneous emission.

3. Maximum Kinetic Energy: Classical physics predicts that the kinetic energy of emitted electrons should depend on the intensity of light, not its frequency. However, the photoelectric effect shows that the maximum kinetic energy depends on the frequency, not intensity.

Quantum Explanation

These aspects are explained by Einstein's quantum theory, which introduces the concept of photons and quantized energy transfer.

8. What is the physical significance of Compton's effect?

Compton's effect demonstrates:

1. Particle Nature of Light: It shows that light behaves as particles (photons) with energy and momentum, rather than just as waves.

2. Momentum Transfer: Compton's effect illustrates the transfer of momentum between photons and particles (electrons), confirming the particle-like behavior of light.

3. Quantum Mechanics Validation: The effect supports the principles of quantum mechanics and the concept of wave-particle duality.

9. Differentiate between Compton's shift and Compton wavelength.

Compton's Shift

Compton's shift refers to the change in wavelength ($\Delta\lambda$) of a photon when it scatters off a free electron. It is given by:

$$\Delta\lambda = \frac{h}{mc}(1 - \cos\theta)$$

Compton Wavelength

Compton wavelength is a constant term ($\frac{h}{mc}$) in the Compton shift formula, representing the wavelength shift when the scattering angle is 90°. It is approximately 0.0243 Å for electrons.

Compton's shift is the actual change in wavelength, while Compton wavelength is a constant factor that determines the magnitude of the shift.

10. How can you say that scattering angle of photon plays effective role in measurement of Compton's shift?

The scattering angle (θ) of the photon plays a crucial role in measuring Compton's shift because:

$$\Delta\lambda = \left(\frac{h}{mc}\right)(1 - \cos\theta)$$

Effect of Scattering Angle

$\theta = 0°$: No shift ($\Delta\lambda = 0$) since $\cos(0°) = 1$.

$\theta = 90°$: Compton shift is equal to Compton wavelength which is $0.0243A^0$ ($\Delta\lambda = h/mc$) since $\cos(90°) = 0$.

$\theta = 180°$: Maximum possible shift ($\Delta\lambda = \frac{2h}{mc}$) since $\cos(180°) = -1$.

The scattering angle directly affects the magnitude of the Compton shift, making it essential for experimental measurements and verification of the Compton effect.

11. What are the conditions required for pair production to occur?

Pair production requires:

1. High-Energy Photon: The photon must have energy greater than or equal to 1.022 MeV, which is the rest mass energy of an electron-positron pair (2 × 0.511 MeV).

2. Presence of a Nucleus: The photon interaction typically occurs near a nucleus, which helps conserve momentum during the pair production process.

12. What is meant by de Broglie wavelength?

The de Broglie wavelength is the wavelength associated with a particle, given by:

$$\lambda = \frac{h}{p}$$

where:

- λ is the de Broglie wavelength

- h is Planck's constant

- p is the momentum of the particle

Significance

The de Broglie wavelength highlights the wave-particle duality, suggesting that particles like electrons exhibit wave-like behavior.

13. Which phenomenon provides evidence for particulate nature of eltromagnetic radiation?

The Photoelectric Effect, Compton effect and pair production are the phenomenon that provides strong evidence for the particulate nature of electromagnetic radiation. It demonstrates that light behaves as discrete particles (photons) with quantized energy, rather than just as waves.

The photon's particle-like behavior is evident in the way it transfers energy to electrons, supporting the idea that electromagnetic radiation has a particulate nature.

Numerical problems

1. In an experiment, the work function of potassium surface is found to be 2.1eV. what should be the wavelength of incident radiation if the stopping potential for the electron is 0.43V?

Given:

Work Function (ϕ) = 2.1 eV

$h = 6.626 \times 10^{-34}$ J·s

$c = 3.00 \times 10^{8}$ m/s

$1 \text{ eV} = 1.602 \times 10^{-19}$ J

Stopping Potential (V_s) = 0.43 V

K.E = eV_s = 0.43 eV

Using the photoelectric equation:

E = ϕ + K.E = 2.1 eV + 0.43 eV = 2.53 eV

Energy of a photon is related to wavelength by:

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

$$\Rightarrow \lambda = \frac{hc}{E}$$

Convert E to joules:

E = $2.53 \times 1.602 \times 10^{-19} = 4.052 \times 10^{-19}$ J

$\lambda = (6.626 \times 10^{-34} \times 3.00 \times 10^{8}) / (4.052 \times 10^{-19}) \approx 4.91 \times 10^{-7}$ m

2. Light of wavelength 5000A⁰ falls on a metal surface having work function of 1.9eV. find (a) energy of photon in electron volt. (b) Kinetic energy of photon- electrons emitted. (c) Stopping potential.

Given:

Wavelength (λ) = 5000 Å = 5000×10^{-10} m = 5×10^{-7} m

Work function (ϕ) = 1.9 eV

h = 6.626×10^{-34} J·s, c = 3×10^{8} m/s, 1 eV = 1.602×10^{-19} J

Solution:

(a) Energy of the photon (E):

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

E = $(6.626 \times 10^{-34} \times 3 \times 10^{8}) / (5 \times 10^{-7}) = 3.9756 \times 10^{-19}$ J

Convert to eV:

E = $(3.9756 \times 10^{-19}$ J$) / (1.602 \times 10^{-19}$ J/eV$) \approx 2.48$ eV

(b) Kinetic Energy of photoelectrons:

K.E. = E - ϕ = 2.48 eV - 1.9 eV = 0.58 eV

K.E. ≈ 0.58 eV

(c) Stopping Potential:

V_0 = K.E. = 0.58 V

3. Calculate the energies of the photons associated with the (I) violet light of 413nm. (ii) X-rays of 0.1nm. (iii) radio waves of 10m

Given

$h = 6.626 \times 10^{-34}$ J s

$c = 3 \times 10^{8}$ m/s

Solution:

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

(i) Violet Light

$\lambda = 413 \text{ nm} = 413 \times 10^{-9}\text{m}$

$E = (6.626 \times 10^{-34} \text{ J s} \times 3 \times 10^{8}\text{m/s}) / (413 \times 10^{-9} \text{ m})$

$= 4.81 \times 10^{-19}\text{J}$

≈ 3 eV

(ii) X-rays

$\lambda = 0.1 \text{ nm} = 0.1 \times 10^{-9} \text{ m} = 10^{-10} \text{ m}$

$E = (6.626 \times 10^{-34} \text{ J s} \times 3 \times 10^{8} \text{ m/s}) / (10^{-10} \text{ m})$

$= 1.988 \times 10^{-15}\text{J} = 1.988\times10^{-15}\text{J}/1.6\times10^{-19}\text{J}$

≈ 12.4 keV

(iii) Radio Waves

$\lambda = 10$ m

$E = (6.626 \times 10^{-34} \text{ J s} \times 3 \times 10^{8} \text{ m/s}) / (10 \text{ m})$

$= 1.988 \times 10^{-25} \text{ J} = 1.988 \times 10^{-25} \text{ J}/1.6\times10^{-19}\text{J}$

$\approx 1.24 \times 10^{-6}$ eV

4. Calculate the minimum energy required by a photon to transfer half of it's energy to an electron at rest.

$mc^2 = (9.1\times10^{-31}\text{kg})\ (3.0\times10^{8})^2 \approx 511$ keV (rest energy of an electron)

$E = \frac{E}{2}$

E = 511 keV / 2 ≈ 255.5 keV or 0.255MeV

5. An electron is placed in a box about the size of an atom that is about 1A⁰. What is the velocity of the electron?

Uncertainty Principle

$\Delta x \times \Delta p \approx \frac{h}{2\pi}$

Given

$\Delta x = 1$ Å $= 10^{-10}$ m

$\Delta p = (6.626\times10^{-34}Js)/ (2) (3.14) (10^{-10}m)$

$\Delta p = 6.626\times10^{-24}Ns$

$m\Delta v \approx 6.626\times10^{-24}Ns$

$\Delta v \approx (6.626\times10^{-24}Ns)/(9.1\times10^{-31}kg)$

$\Delta v \approx 7.29\times10^{6}m/s$

6. A 50keV X-ray is scattered through an angle o 90⁰ what is the energy of the X-ray after Compton scattering?

Step 1: Find the initial wavelength

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

$\lambda = \frac{(6.63\times10-^{34}Js)\ (3\times10^{8})}{E} \quad = \quad \frac{19.89\times10-^{26}}{E} \quad ==>> \frac{19.89\times10^{-26}}{50 \text{ x } 10^{3} \text{ x } 1.6\times10^{-19}}$

λ = 0.248 Å

Step 2: Calculate the Compton shift

$\Delta\lambda = \frac{h}{mc}(1 - \cos\theta)$

The term h/mc is known as the Compton wavelength of the electron, which is approximately 0.0243 Å.

For θ = 90°, cos (90°) = 0.

Δλ = 0.0243 Å × (1 - 0)

Δλ = 0.0243 Å

Step 3: Find the final wavelength*

λ' = λ + Δλ

λ' = 0.248 Å + 0.0243 Å

λ' = 0.2723 Å

Step 4: Calculate the final energy

$E' = \frac{hc}{\lambda'}$

E' = 12.4 keV Å / 0.2723 Å

E' ≈ 45.5 keV

Assignments

21.1.What will be photon energy for a wavelength of 5000A⁰, if energy of a photon corresponding to wavelength of 7000A⁰ is 4.23×10^{-19}J?

Given:

$E1 = 4.23 \times 10^{-19}$J for $\lambda1 = 7000$ Å $= 7 \times 10^{-7}$ m

$\lambda2 = 5000$ Å $= 5 \times 10^{-7}$ m

Solution:

Relationship Between Energy and Wavelength

$$E \propto \frac{1}{\lambda}$$

$$E_1 / E_2 = \frac{\lambda_2}{\lambda_1}$$

$$E_2 = E_1 \times \frac{\lambda_1}{\lambda_2}$$

$E_2 = 4.23 \times 10^{-19}$ J $\times$ (7×10^{-7}m / 5×10^{7} m)

$E_2 = 4.23 \times 10^{-19}$ J $\times$ 1.4

$E_2 = 5.922 \times 10^{-19}$ J

21.2. Radiation of wavelength 3000A⁰ falls on a photoelectric surface for which work function is 1.8eV. what is stopping potential for emitted electron?

Given:

$\lambda = 3000$ Å $= 3 \times 10^{-7}$m

W = 1.8 eV = $1.8 \times 1.602 \times 10^{-19}$ J = 2.88×10^{-19} J

Photon Energy

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

E = (6.626×10^{-34} Js $\times$ 3×10^{8}m/s) / (3×10^{-7}m)

E = 6.626×10^{-19}J

Converting to eV:

E = 6.626×10^{-19}/ (1.602×10^{-19}) ≈ 4.13 eV

Maximum Kinetic Energy

$K_{max} = E - \Phi$

K_{max} = 4.13 eV - 1.8 eV = 2.33 eV

Stopping Potential

$eV_0 = K_{max}$

$V_0 = K_{max} / e$ = 2.33 eV / e = 2.33 V

21.3. An X-ray of 71pm is incident on a target. What is the smallest shift that can be expected at 60⁰? Find wavelength of scattered X-ray.

Given:

$\lambda = 71$ pm $= 71 \times 10^{-12}$m

$\theta = 60°$

h = 6.626×10^{-34} Js

$m_0 = 9.11 \times 10^{-31}$kg (electron rest mass)

c = 3×10^{8} m/s

Solution:

$$\Delta\lambda = \frac{h}{m_0c} \times (1 - \cos\theta)$$

$\Delta\lambda = \frac{6.626 \times 10^{-34}\ \text{Js}}{9.11 \times 10^{-31}\ \text{kg} \times 3 \times 10^{8}\text{m/s}} \times (1 - \cos 60°)$
$\Delta\lambda = (2.426 \times 10^{-12}\ \text{m}) \times (1 - 0.5)$
$\Delta\lambda = (2.426 \times 10^{-12}\ \text{m}) \times 0.5$
$\Delta\lambda = 1.213 \times 10^{-12}\text{m}$
$\Delta\lambda = 1.213\ \text{pm}$
Scattered X-ray Wavelength
$\lambda' = \lambda + \Delta\lambda$
$\lambda' = 71\ \text{pm} + 1.213\ \text{pm}$
$\lambda' \approx 72.213\ \text{pm}$
21.4. The speed of riffle bullet is 1500m/s. If it's mass is 20g then find the de Broglie wavelength associated with it. If this wavelength observable? Give reason.
Given:
$v = 1500\ \text{m/s}$
$m = 20\ \text{g} = 0.02\ \text{kg}$
$h = 6.626 \times 10^{-34}\ \text{Js}$
Solution:
De Broglie Wavelength Formula
$\lambda = \frac{h}{mv}$
$\lambda = 6.626 \times 10^{-34}\ \text{Js} / (0.02\ \text{kg} \times 1500\ \text{m/s})$
$\lambda = 6.626 \times 10^{-34}\ \text{Js} / 30\ \text{kg·m/s}$
$\lambda = 2.2087 \times 10^{-35}\ \text{m}$
The calculated wavelength (2.21×10^{-35}m) is extremely small, far beyond the resolution of current technology.
Due to its tiny size, the wave-like behavior of the bullet is not observable, and its particle-like behavior dominates.
21.5. Let's consider a ball with mass 0.1kg moving at speed of 30m/s. The uncertainty in it's momentum is 0.000001 of it's actual momentum. Determine uncertainty in it's position.
Given:
$m = 0.1\ \text{kg}$
$v = 30\ \text{m/s}$
$\Delta p = 0.000001 \times p$
$h = 6.626 \times 10^{-34}\ \text{Js}$
Solution:
$p = mv = 0.1\ \text{kg} \times 30\ \text{m/s} = 3\ \text{kgm/s}$
$\Delta p = 0.000001 \times 3\ \text{kg·m/s} = 3 \times 10^{-6}\text{kgm/s}$
Uncertainty Principle Formula
$\Delta x \times \Delta p >= h / (4\pi)$
$\Delta x \approx h / (4\pi \times \Delta p)$
$\Delta x \approx 6.626 \times 10^{-34}\ \text{Js} / (4 \times 3.14159 \times 3 \times 10^{-6}\ \text{kgm/s})$
$\Delta x \approx 1.76 \times 10^{-29}\text{m}$

CHAPTER 22 Nuclear Physics

MULTIPLE CHOICE QUESTIONS

Encircle the Correct option.

1.The process by which a heavy nucleus splits into two smaller nuclei is called:

A. Fission B. Fusion C. Alpha decay D. Beta decay

ANS

A. Fission

2. Radiation with highest ionizing power is:
A. Gamma rays B. X-rays C. Alpha particle D. Beta particle
ANS
C. Alpha particle

3. Which of the following particles has almost the same mass as a proton but carries no charge:
A. Neutron B. Proton C. Electron D. Beta particle
ANS
A. Neutron

4. The charge on an alpha particle is:
A. –1 B. -2 C. +1 D. +2
ANS
D. +2

5. In the nucleus of uranium-235, the number of neutrons is:

A. 92 B. 143 C. 235 D. 134

ANS

B. 143

Reason: Uranium-235 has atomic number 92 → Neutrons = 235 - 92 = 143

6. The half-life of radium is 1590 years. In how many years shall the Earth lose all its radium due to radioactive decay?

A. 795 B. 1590 C. 3180 D. Infinite

ANS

D. Infinite

7. The energy released in nuclear reactor is produced by:

A. Fission B. Fusion C. Coal D. Gas

ANS

A. Fission

8. C-14 has a half-life 5730 years. The number of nuclei in a sample will drop to 1/8 of initial quantity in ______ years:

A. 1.44×10^4 B. 1.72×10^4 C. 2.58×10^4 D. 2.85×10^4

ANS

B. 1.72×10^4

Reason: 1/8 means 3 half-lives → $5730 \times 3 = 17190 \approx 1.72 \times 10^4$

Conceptual short question of chapter 22

Give short answers of the following questions.

1. What are the benefits and drawbacks of nuclear energy compared to other forms of energy?

ANS;

Benefits:

• Produces a large amount of energy from a small amount of fuel.
• Does not release greenhouse gases during operation.
• Provides continuous power supply (not weather dependent)

Drawbacks:

• Produces radioactive waste that needs long-term storage.
• Risk of nuclear accidents.
• Very high construction and maintenance cost.

2. What is the effect on atomic and mass numbers during the following processes?

(a) Electron Emission (β^- decay) (b) Electron Capture
(c) Alpha (α) Particle Emission

ANS;

(a) Electron emission (β^- decay)

Atomic number increases by 1, as a neutron changes to a proton
Mass number stays the same

(b) Electron capture:

Atomic number decreases by 1, as a proton captures an electron and becomes a neutron

Mass number stays the same.

(c) Alpha (α) particle emission:
Atomic number decreases by 2 (loss of 2 proton)
Mass number decreases by 4 (loss of 2 protons + 2 neutrons)

3. Why does an alpha particle not reach the nucleus even when directed toward it?
ANS
An alpha particle does not reach the nucleus due to the strong electrostatic repulsion between the positively charged alpha particle and the positively charged nucleus.
Unless the alpha particle has extremely high energy, it cannot overcome this repulsive Coulomb barrier. Therefore, it gets deflected before reaching the nucleus. Only at very high speeds or via quantum tunneling can an alpha particle approach or penetrate the nucleus.

4. An alpha particle has twice the charge of a beta particle. Why does the former deflect less than the latter when passing between electrically charged plates, assuming they both have the same speed?
ANS
Although the alpha particle has more charge (+2e), it has a much greater mass than a beta particle (electron). Deflection depends on the charge-to-mass ratio (q/m). The alpha particle's large mass causes less acceleration and deflection.
In contrast, the beta particle is much lighter and has a higher q/m ratio, so it deflects more in the electric field.

5. Why does uranium fuel need to be enriched before use?
ANS
Natural uranium contains about 99.3% U-238 and only 0.7% U-235. Only U-235 is fissile and can sustain a nuclear chain reaction. U-238 is not fissile with slow neutrons. Therefore,
uranium must be enriched to increase the percentage of U-235 (usually to 3–5%) so it can be used effectively as nuclear fuel in reactors.

6. If U-238 undergoes alpha decay, what is the resulting nucleus?
ANS
When uranium-238 ($^{238}_{92}U$) undergoes alpha decay, it emits an alpha particle ($^{4}_{2}He$), which has 2 protons and 2 neutrons.

Resulting nucleus:

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

So, the resulting nucleus is thorium-234 ($^{234}_{90}Th$).

7. How do chain reactions occur in nuclear fission?
ANS
In nuclear fission, a heavy nucleus like U-235 splits into two lighter nuclei when struck by a neutron, releasing energy and more neutrons. These released neutrons strike other U-235 nuclei, causing more fissions. This process continues in a self-sustaining manner, called a chain reaction. For control, moderators and control rods are used in reactors.

8. How does the molecular weight difference between U-235 and U-238 hexafluoride molecules enable enrichment? What role do porous barriers play in the gaseous diffusion process?

ANS

The enrichment of uranium is possible due to the small difference in molecular weight between uranium-235 (U- 235) and uranium-238 (U-238) when they are in the form of uranium hexafluoride gas (UF_6). U-235 is slightly lighter than U-238, so its UF_6 molecules move a bit faster. In the gaseous diffusion process, this UF_6 gas is passed through porous barriers that have tiny holes. Because U-235 molecules are lighter, they pass through the pores slightly faster and more easily than U-238. Each time the gas passes through a barrier, the concentration of U-235 increases just a little. Repeating this process over many stages gradually enriches the uranium in U-235. The porous barriers play a very important role by allowing this slow and steady separation based on mass difference between the isotopes..

Numerical Problems

1. If an isotope has a half-life of 10 days and there are initially 5000 nuclei, how many will remain after 30 days?

Given:

Half-life ($t_{1/2}$) = 10 days

Initial nuclei (N_0) = 5000

Total time (t) = 30 days

Solution:

Calculate number of half-lives:

$n = t / t_{1/2} = 30 / 10 = 3$

Calculate remaining nuclei:
$N = N_0 \times (1/2)^n = 5000 \times (1/2)^3 = 5000 \times 1/8 = 625$
Answer: 625 nuclei

2. A nucleus of carbon-14 has a decay constant of 0.00012 s^{-1}. What is its half-life?
Given Data:
Decay constant (λ) = 0.00012 s^{-1}
Solution:
Calculate half-life:
$t_{1/2} = \ln(2)/\lambda = 0.693/0.00012 \approx 5775$ s
Answer: 5775 seconds

3. Calculate the energy released when a nucleus of U-235 undergoes fission and releases two neutrons.
Given:
Mass of neutron ($^{1}_{0}n$) = 1.008665 u
Mass of U-235 ($^{235}_{92}U$) = 235.0439299 u
Mass of Ba-141 ($^{141}_{56}Ba$) = 140.914411 u
Mass of Kr-92 ($^{92}_{36}Kr$) = 91.926156 u
1 atomic mass unit (u) = 931.5 MeV/c^2
1 MeV = 1.60218×10^{-13} J

Solution:
$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 2\,^{1}_{0}n + \text{Energy}$
Initial Mass = Mass of neutron + Mass of U-235
= 1.008665 u + 235.0439299 u
= 236.0525949 u

Final Mass = Mass of Ba-141 + Mass of Kr-92 + 2 × Mass of neutron
= 140.914411 u + 91.926156 u + 2(1.008665 u)
= 234.857897 u

Δm = Final Mass - Initial Mass
= 234.857897 u - 236.0525949 u
= -1.1946979 u

$E = \Delta m \times 931.5$ MeV/u
= -1.1946979 u × 931.5 MeV/u
= -1112.86 MeV
1 MeV = 1.60218×10^{-13} J
$E = -1112.86 \times 1.60218 \times 10^{-13}$
= -1.7825×10^{-10} J
Answer:
The energy released is -1112.86 MeV or -1.7825×10^{-10} J

4. Calculate the number of nuclei of C-14 remaining after 40,110 years if initially there were 10,000 atoms.The half-life of C-14 is 5,730 years.

Given Data:
Initial nuclei (N_0) = 10,000
Half-life ($t_{1/2}$) = 5,730 years
Total time (t) = 40,110 years

Solution
Calculate number of half-lives:
$n = t / t_{1/2} = 40,110 / 5,730 \approx 7$

Calculate remaining nuclei:
$N = N_0 \times (1/2)^n = 10{,}000 \times (1/2)^7 = 10{,}000 \times 1/128 \approx 78.125$
Note: The provided answer of 4670 appears incorrect based on this calculation.
Answer: 78 nuclei

5. Calculate the mass defect and binding energy per nucleon for silver (Ag) with atomic mass 107.905949 u.
Given Data:
Atomic mass of Ag = 107.905949 u
Mass of proton = 1.007276 u
Mass of neutron = 1.008665 u
Solution:
For Ag-108:
Protons (Z) = 47
Neutrons (N) = 61

Calculate total nucleon mass:
$= (47 \times 1.007276) + (61 \times 1.008665) = 108.870537$ u
Calculate mass defect:
$\Delta m = 108.870537 - 107.905949 = 0.964588$ u
Calculate binding energy:
$E = \Delta m \times 931.5$ MeV/u ≈ 898.5 MeV
Binding energy per nucleon:
$= 898.5$ MeV / 108 ≈ 8.32 MeV/nucleon
$= 1.33 \times 10^{-12}$ J/nucleon
Answer: 1.33×10^{-12} J/nucleon

6. Calculate the energy released in the reaction:

$^{1}_{0}n + ^{238}_{92}U \rightarrow ^{96}_{38}Sr + ^{140}_{54}Xe + 3^{1}_{0}n + Q$

Given Data:

Mass of neutron = 1.008665 u

Mass of ^{238}U = 238.050788 u

Mass of ^{96}Sr = 95.921750 u

Mass of ^{140}Xe = 139.921640 u

Solution:

Initial mass:

= 1.008665 + 238.050788 = 239.059453 u

Final mass:

= 95.921750 + 139.921640 + 3(1.008665) = 238.869385 u

Mass defect:

Δm = 238.869385 - 239.059453 = -0.190068 u

Energy released:

E = (-0.190068 u) × (931.5 MeV/u) = -177.0 MeV

= -177.0 × 1.60218 × 10^{-13} J = -2.835 × 10^{-11} J

Answer: -2.835 × 10^{-11} J

Exercise

Encircle the correct options.

1. SI unit of Luminosity is:

A.watts B. joules

C.newtons/meter D. cd/m

2. Luminosity is associated with energy produced by

A.objects B.celestial bodies

C.light source D.fluorescent lamp

3. Luminosity depends on

A.size of star B.Temperaure of star

C.colour of the star D.Option 1 and 2

4. Which law states that brightness of a source is inversely proportional to the square of its distance

A.Law of brightness B.Direct square law of brightness

C.Inverse square law of brightness D.Inverse square law of light

5. SI unit of Hubble's constant (H_o) is

A.s^{-1} B.m^{-1}

C.m D.ms^{-1}

6. Which statement about the Big-Bang theory is not correct

A.There is a giant explosion known as big bang

B.This caused the universe to expand from a single source

C.Each point in the universe away from a single source

D.The further away galaxies are slower they are moving

Short Questions

1. What is meant by blackbody radiations?

A blackbody is an idealised physical body that absorbd all radiations incident upon it and emit radiations all wavelengths. It does not reflect or trasmit light.

Consider a non-reflecting object such as a solid with a hollow cavity with in it, radiations can enter or leaves the body through hole. It will absorb all the incident electromagnet radiations and emits radiations solely based on temperature. The spectrum of these emitted radiations only depends upon its temperature.

2. What is the relationship between luminosity and radiant flux intensity?

Luminosity(L) is a measure of total power output of radiation emitted by a celestial body(star), measured in watts. Radiant flux intensity (F), also known as apparent brightness , is power received per unit area at a certain distance from an object, measured in watts/m^2 .

Mathematically Luminosity and radiant flux intensity is related as:

$$\boldsymbol{F = \frac{L}{A} = \frac{L}{4\pi d^2}}$$

Where d is distance from object.

This relation shows that flux intensity decreases with square of distance from source.

3. What is inverse square law for radiant flux intensity?

The inverse square law for radiant flux intensity states that radiant flus intensity(F) received from a point source of light is inversely proportional to the square of distance(d) from the source.

Mathematically;

$$F \propto \frac{1}{d^2}$$

If we double the distance from a light source, the percieved brightness(flux intensity) will be four times.

4. What is meant by standard candles? Give any two examples

A standard candle is defined as an astronomical object that has known and consistent intrinsic luminosity. By comparing their characteristic quality which is possessed by the class of object, astronomers can determine their distance. In this way, they are able to make crucial tools for measuring cosmic distances.

Examples: type Ia supernova and Cepheid variable stars

5. What is Wien's displacement law?

Wien's displacement law describes the relationship between the peak wavelength of emitted radiation from a blackbody and its temperature. It states that the wavelength at which the maximum intensity of radiation is emitted(λ_{max}) is inversely proportional to absolute temperature(T) of the blackbody.

Mathematically:

$$\lambda_{max} = \text{Constant}\,\frac{1}{T}$$

here the constant is equal to 2.989×10^{-3}mK. So equation for Wien's displacement law becomes

$$\lambda_{max}T = 2.989\times10^{-3}\text{mK}$$

this means that hotter objects emit light at shorter wavlengths(e.g blue light) and cooler objects emits light at longer wavelengths(e.g redder light).

6. Define Stefen-Boltzmann Law.

It states the total energy radiated per unit surface area per unit time is directly proportional to the fourth power of absolute temperature of the body.

Mathemaically:

$$\frac{E}{At} \propto T^4$$

$$\frac{E}{At} = \sigma T^4$$

or

$$\frac{E}{t} = A\sigma T^4$$

or

$$P = A\sigma T^4$$

or

$$L = A\sigma T^4$$

Where L is luminosity, P is power radiated, A is surface area , T is absolute temperature and σ is stefen-Boltzmann constant(5.67×10^{-8} $Wm^{-2}K^{-4}$)

If Area of celestial body is considered as spherical then

$$L = 4\pi r^2 \sigma T^4$$

Where r is radius of body.

This law explains why hotter bodies radiate more energy.

7. How can we estimate radius of a star by applying Wien's displacement law and Stefen-Boltzmann law?

To estimate star's radius:

Temperature(T): Use Wien's displacement law ($\lambda_{max}T= 2.989\times10^{-3}mK$) by observing the star's peak emission wavelength(λ_{max}) to find the surface Temperature T.

Luminosity(L): Determine the star's luminosity(L) from its apparent brightness and distance(if known, often using standard candles)

Radius(R): Apply the Stefen-Boltzmann law ($L = 4\pi r^2 \sigma T^4$). With L, T and σ known.

The radius can be calculated using expression:

$$R = \sqrt{L/4\pi\sigma T^4}$$

8. How redshift lead to the idea that universe is expanding?

Redshift is defined as: the fractional increase in wavelength (or decrease in frequency) due to the source and observer receding from each other or light from distant galaxies appears to be shifted towards the red end of electromagnetic spectrum.
This shift occurs due to Doppler's effect, indicating that these galaxies are moving away from us. The further away the galaxy is, the greater is observed redshift, imply a greater recessional velocity. This systematic observation of redshift from almost all distant galaxies provide strong evidence that the entire universe is expanding.

9. How does expansion of of universe support Big Bang theory?

The expansion of the universe supports the Big Bang Theory by showing that the universe had a beginning.

Galaxies are moving apart

Scientists observe that distant galaxies are moving away from us. This means the universe is expanding in all directions. The farther away a galaxy is, the faster it is moving (Hubble's Law).

Rewinding the expansion

If the universe is expanding now, then in the past, it must have been smaller and denser.
If we go far back in time, all matter and energy would have been compressed into a single point, this is the idea of the Big Bang.

Supports a beginning

Expansion shows the universe is not static or eternal.
It began from a hot, dense state and has been expanding ever since.
So it is true, the universe likely began in an extremely hot, dense singular point which subsequently began to expand very quickly. This gives direct evidence that the universe had a starting point, which is exactly what the Big Bang Theory explains.

10. How do different types of spectra (emission, absorption, continuous) provides insights into the comparison and properties of celestial objects?

Different types of spectra (emission, absorption, and continuous) provide powerful tools for astronomers to understand and compare the composition, temperature, motion, and physical properties of celestial objects.

- **Continuous Spectrum**

It is a smooth, uninterrupted band of colors (like a rainbow) emitted by a dense, hot object (e.g., a star’s surface).
It reveals about the following properties of celestial objects:
<u>Temperature:</u> The peak wavelength helps determine surface temperature using Wien's Law.
<u>Energy output:</u> Helps calculate total energy radiated (luminosity) via Stefan-Boltzmann Law.
By comparison of these characters we come to know that Hotter stars peak at shorter wavelengths (blue), cooler ones at longer wavelengths (red).

- **Emission Spectrum (Bright Lines)**

It gives bright lines at specific wavelengths produced when electrons in atoms drop to lower energy levels and emit photons. It is observed in hot, low-density gases like nebulae or gas around young stars.
It reveals following properties:
<u>Elemental composition:</u> Each element has a unique spectral "fingerprint."
<u>Temperature and density of gas</u>**:** Line intensity and width provide clues.
By these characters we come to identify chemical makeup of distant galaxies or nebulae.

- **Absorption Spectrum (Dark Lines)**

It is a continuous spectrum with dark lines at specific wavelengths, created when light passes through a cooler gas that absorbs certain wavelengths. It is observed in light from stars passing through their cooler outer layers or interstellar medium.
It reveals about:
<u>Chemical composition:</u> Dark lines show what elements are present in the star’s atmosphere.

Surface temperature: Certain absorption lines are stronger at certain temperatures.
Motion: Doppler shifts in line positions indicate motion (toward or away from us).
By comparing these factors we can classify stars based on line patterns and strength.

Numerical Problems

1. There are two stars, let named A and B. which star has greater temperature? Giwn that: $L_A=L_B=10^4$ m; $R_A=10^4$ and $R_B=10^5$ m.

Solution:

Using Stefen-Boltzmann law;

$$\frac{L_A}{L_B}=\frac{R_A^2}{R_B^2}\frac{T_A^4}{T_B^4}$$

As $L_A=L_B$

$$\frac{T_B^4}{T_A^4}=\frac{R_A^2}{R_B^2}$$

$$\frac{T_B}{T_A}=\left(\frac{10^8}{10^{10}}\right)^{1/4}=10^{-1/2}$$

$$\frac{T_A}{T_B}=3.1$$

$$T_A=3T_B$$

T_A is at higher temperature.

2. The sun has a surface temperature of 6000K produces peak radiation of 420 nm. Find out the temperature of Sirius if peak radiation of Sirius is 72 nm.

Usig Wien's displacement law;

$\lambda_{sun}T_{sun}=\lambda_{siris}T_{siris}$

$420\times10^{-9}\times6000=72\times10^{-9}\times T_{siris}$

$T_{siris}=35000K$

3. If a source has a luminosity of 3.826×10^{26} W and is at distance of 3 light years, what is radiant flux intensity?

Distance=d=3 light years

In meters

d= 3×3×10^{8}×3.1×10^{7}

d= 2.8×10^{16}m

from definition of Radiant-flux intensity

$$F = \frac{L}{4\pi d^2}$$

$$F = \frac{3.8\times10^{26}}{4(3.14)(2.8\times10^{16})^2}$$

$$F = 3.8\times10^{-8}\ Wm^{-2}$$

Assignment 1:

What is the relative luminosity of the objects A and B if: T_A=100K, T_B= 200 K, R_A = 10 m and R_B= 5 m

According to Stefen-Boltzmann law;

$$\frac{L_A}{L_B} = \frac{R_A^2 T_A^4}{R_B^2 T_B^4}$$

$$\frac{L_A}{L_B} = \frac{(10)^2(100)^4}{(5)^2(200)^4}$$

$$\frac{L_A}{L_B} = \frac{1}{4}$$

$$L_B = 4L_A$$

Assignment 2:

Betalgeuse is our nearest red giant star. It has the luminosity of 4.40 × 10^{31} W and emits radiation with peak wavelength of 850 nm. Calculate the ratio of the radius of Betelgeuse r_B to the radius of Sun r_s.

L_B=4.49×10^{31} W

Λ_B=850×10^{9} m

$$\frac{r_B}{r_S} = ?$$

Using Stefen-Boltzmann law

$$\frac{L_B}{L_S} = \frac{r_B^2 T_B^4}{r_S^2 T_S^4}$$

$$\frac{T_S^4 L_B}{T_B^4 L_S} = \frac{r_B^2}{r_S^2}$$

As T_B is unknown

Using Wien's displacement law

$$\lambda_{max} T_B = 2.989\times10^{-3}\,\text{mK}$$

$$T_B = 2.989\times10^{-3}/850\times10^{-9}$$

$$T_B = 3410\,\text{K}$$

Estimated values for L_s and T_s are;

$L_s = 3.8\times10^{26}$ W

$T_s = 5778$ K

By using all these values in above equation:

$$r_B = 983\, r_s$$

Assignment 3:

A galaxy is found to be moving away with a speed of 2.1×10^{7} ms^{-1}. The galaxy is at a distance of 9.5×10^{24} m from Earth. Assuming the speed has remained constant, what is the universe in years.

As

$$Time = \frac{Distance}{Speed}$$

$$t = \frac{9.5 \times 10^{24}}{2.1 \times 10^{7}}$$

$$t = 4.5 \times 10^{17} s$$

$$t = 4.5 \times 10^{17} \times 0.32 \times 10^{-7} years$$

$$t = 1.45 \times 10^{10} years$$
$$t = 14.5\ Billion\ years$$

PUNJAB COLLEGE D-9 CAMPUS RAWALPINDI

CHAPTER 24: EARTH'S CLIMATE

1. Which of the following gases has the maximum contribution to global warming?

A. Chlorofluorocarbons B. Methane C. Sulfur hexa-fluoride D. Carbon dioxide

2. Which of the following gas is not responsible for global warming?

A. NO_2 **B. H_2O** C. SO_2 D. CO_2

3. In global warming, the temperature of ....increases?

A. Troposphere B. Ionosphere C. Mesosphere D. Stratosphere

4. Which type of climate is found in our country Pakistan?

A. Tundra B. Equatorial **C. Monsoon** D. Western

5. What is the height of Troposphere near the poles and equator in kilometers?

A. 8 and 18 B. 6 and 16 **C. 4 and 16** D. 10 to 20

6. What happens in the Ionosphere?

A. Meteors B. Aero planes fly **C. Radio waves reflected** D. Satellites move

7. Which atmospheric layer contains ions and helps in wireless communications?

A. **Ionosphere** B. Thermosphere C. Mesosphere D. Stratosphere

8. The part of the Earth atmosphere contains about 70% of the total air in the atmosphere is?

A. **Troposphere** B. Thermosphere C. Mesosphere D. Stratosphere

9. Hot and dry winds blowing in the northern plains of Punjab and Sindh are:

A. Trade winds **B. Loo** C. Westerlies D. Easterlies

10. Pakistan is located in the region of........... winds?

A. Trade B. North Easterlies **C. Westerlies** D. South Easterlies

Short Questions-

Q1. Where in the atmosphere is water vapor most concentrated and why?

Water vapor is most concentrated in the troposphere, which is the lowest layer of Earth's atmosphere, especially near the Earth's surface. This is because the troposphere contains almost all the atmospheric water vapor due to its proximity to sources of evaporation like oceans, lakes, and rivers, and it also has higher temperatures that allow more water to remain in the vapor form. As altitude increases, the temperature drops, making it harder for air to hold moisture, so the concentration of water vapor decreases sharply with height.

Q2. What is the difference between the weather and the climate?

Weather and climate both describe atmospheric conditions but differ in timescale and scope. Weather refers to the short-term conditions of the atmosphere—such as temperature, humidity, wind, precipitation, and cloudiness—that occur over hours or days in a specific location. In contrast, climate is the long-term average of weather patterns over a much larger region, typically measured over 30 years or more. While weather is what you experience day-to-day (like a sudden thunderstorm or a hot afternoon), climate is what you expect (like snowy winters in Canada or dry deserts in the Middle East). Essentially, weather tells you what to wear today, climate tells you what clothes to own.

Q3. Warm air has a greater capacity to hold water vapors. Why?

Warm air has a greater capacity to hold water because increasing temperature gives air molecules more kinetic energy, allowing them to move faster and spread out. This reduces the air's density and creates more space between molecules, enabling more water molecules (in the form of vapor) to fit in. Additionally, higher temperatures provide the energy needed to break hydrogen bonds in liquid water, encouraging more evaporation. As a result, warmer air can hold significantly more water vapor before reaching saturation compared to cooler air.

Q4. How does the atmosphere retain itself?

The atmosphere retains itself primarily due to Earth's gravity, which pulls gas molecules toward the surface and prevents them from drifting into space. Despite being made of light gases like nitrogen and oxygen, gravity is strong enough to hold these molecules close, especially in the lower layers like the troposphere. Additionally, Earth's relatively cool temperature and the planet's magnetic field help protect the atmosphere from being stripped away by solar wind. The continuous recycling of gases through natural processes like respiration, volcanic activity, photosynthesis, and evaporation also sustains the balance and composition of the atmosphere over time.

Q5. Describe global latitudinal air movements due to the uneven heating at different latitudes?

Global latitudinal air movements arise from the uneven heating of Earth's surface, where the equator receives more direct solar energy than the poles. This causes warm air at the equator to rise, creating a low-pressure zone, and flow toward the poles in the upper atmosphere. As it cools, it sinks around 30° latitude in both hemispheres, forming high-pressure zones and creating the Hadley cells. From these zones, surface air moves back toward the equator as trade winds. Between 30° and 60°, the Ferrel cells operate with mid-latitude westerlies, while at the poles, cold dense air sinks and moves toward the equator as polar easterlies, forming the polar cells. These three major convection cells in each hemisphere drive the global circulation system, distributing heat, moisture, and influencing climate patterns.

Q6. What would be the consequences if all the polar ice melts?

If all the polar ice melts, global sea levels would rise by about 70 meters, submerging major coastal cities and displacing hundreds of millions of people worldwide. Vast low-lying regions, including parts of Bangladesh, Florida, and entire island nations, would disappear underwater, triggering humanitarian and economic crises. The loss of ice would drastically reduce Earth's albedo (reflectivity), absorb more solar heat and accelerate global warming. Ocean currents and weather patterns would shift unpredictably, disrupting agriculture, freshwater supplies, and ecosystems. Polar species like penguins and polar bears would face extinction, while methane released from thawing permafrost could trigger further climate feedback loops, intensifying climate change.

Q7. Is the lithosphere a part of mental? Justify your answer

The lithosphere is not entirely a part of the mantle, but it does include a portion of it. It is the rigid outer layer of the Earth, consisting of the entire crust and the uppermost solid part of the mantle. While the crust is a separate layer above the mantle, the uppermost section of the mantle—about 100 kilometers deep—joins with the crust to form the lithosphere. Therefore, the lithosphere is not the same as the mantle but includes its upper solid part. Beneath the lithosphere lies the asthenosphere, a softer, more plastic layer of the upper mantle that allows the lithospheric plates to move. Thus, the lithosphere is a distinct structural layer that spans both the crust and a portion of the upper mantle.

Q8. What are the four components of the biosphere?

The biosphere consists of four major components: lithosphere, hydrosphere, atmosphere, and biosphere (living organisms) itself. The lithosphere includes the solid outer layer of Earth, such as rocks, soil, and landforms, providing habitat and nutrients. The hydrosphere covers all water bodies—oceans, rivers, lakes, glaciers, and groundwater—that support aquatic life and influence climate. The atmosphere is the layer of gases surrounding Earth, vital for breathing, weather patterns, and climate regulation. Finally, the biosphere (in a narrow sense) refers to all living organisms—plants, animals, and microbes—that interact with these physical components to form a complex, interconnected system essential for life.

Q9. Why Stratosphere is called a calm and stable layer?

The stratosphere is called a calm and stable layer because it lacks the vertical air turbulence found in the lower troposphere. In this layer, the temperature increases with altitude due to the absorption of ultraviolet (UV) radiation by the ozone layer, creating a temperature inversion that discourages vertical air movement. This thermal structure stabilizes the air, preventing convection and resulting in smooth, layered air flow. As a result, weather disturbances and storms are rare, making the stratosphere ideal for long-distance jet travel and the reason it's often described as calm and stable.

Numerical Problems.

1). If the volume of change in storage of the hydrosphere, whose area is $30km^2$ is $600,000m^3$, find net precipitation(P) if the volume of evaporation is $1,500,000m^3$ and runoff volume is $600,000\ m^3$.

Given data

Area= A= 30,000, Change in storage = ΔS= 600000m^3

Evaporation volume=E=1500000m^3, Runoff volume=R=600,000m^3

To find

Net precipitation=P=?

Calculation

We know that

P= E + R + ΔS

P= 1500,000+600,000+600,000

P=2,700,000 m^3

Now, converting volume of precipitation-to-precipitation depth

p= P/A

P= 2,700,000m^3/30,000m^2

P=90m

2. If a Coriolis force of 30N defects a mass of air at 30° moving with a speed of 40km/h. Find the mass of this air packet where w= 7.3 × 10^-5 rad/s.

Given data

F_c =30N, θ= $30^{o,}$ V= 11.11m/s, ω=7.3x10^{-5} rad/s

To Find = m=?

Calculation

We know that

F_c = 2mvω sinθ

$$m=\frac{F_c}{2v\omega \sin\theta}$$

$$m=\frac{30}{2x11.11x7.3x10^{-5}\sin 30} = 369,900Kg$$

CHAPTER # 25 EXERCISES

Multiple Choice Questions

Encircle the Correct option.

1	**Frequency of X-rays depends upon**		
A)	Number of electrons striking target	B)	Accelerating potential
C)	Nature of the Target	D)	**Both B and C**
2	**Target material used in X-rays tube must have following properties**		
A)	**High atomic number and high melting point.**	B)	High atomic number and low melting point.
C)	Low atomic number and low melting point.	D)	High atomic number only.
3	**Which of the following is drawback while conducting a medical imaging test**		
A)	Early detection of problem.	B)	Accurate diagnosis.
C)	Contribution to choose of effective treatment .	D)	**Exposure to radiation.**
4	**In an experiment, high speed electrons emitted from the cathode are accelerated through a potential difference of 20 kV. Find the minimum wavelength of the X-rays produced. (Lake Planck's constant, $h=6.6\times10^{-34}$ Js)**		
A)	0.36782 A^O	B)	**0.61875 A^O**
C)	0.45867 A^O	D)	0.72854 A^O
5	**In an X-ray tube, electrons accelerated through a very high potential difference strike a metal target. If the potential difference is increased, the speed of the emitted X-rays**		
A)	Increases.	B)	Decreases.
C)	**Is always equal to 3.0×10^8 ms^{-1}.**	D)	Increases or decreases depending on the target material.

Short Questions

1) Differentiating Piezoelectric Effect and Inverse Piezoelectric Effect:

	Piezoelectric Effect	**Inverse Piezoelectric Effect**
1	The production of an electric charge in certain materials (like quartz crystals or ceramics) when mechanical stress is applied to them.	The deformation or change in shape of a piezoelectric material when an electric field is applied across it.
2	Input is force, output is electricity.	Input is electricity, output is movement or shape change
3	Used in sensors and microphones.	Used in speakers and ultrasound machines.

2. What is the Distinction between Continuous X-ray and Characteristic X-ray?

ANS. Continuous X-ray (Bremsstrahlung):

It Produces when high-speed electrons are decelerated as they interact with the atomic nuclei of the target material, resulting in a continuous spectrum of X-ray energies.

Characteristic X-ray:

It Produces when an incident electron ejects an inner-shell electron from an atom, and an outer-shell electron fills the vacancy, emitting an X-ray photon with a specific energy characteristic of the element.

3. What is the Purpose of an X-ray?

i)To check broken bones (fractures).

ii)To find problems in teeth (like cavities).

iii)To detect tumors or cancers.

Iv)To guide doctors during surgeries or treatments.

V)To locate objects inside the body (like swallowed items).

4. X-rays can emit electrons from metal surfaces and X-rays can be diffracted. Comments

ANS. X-rays emitting electrons (Photoelectric Effect):

When X-ray photons strike a metal surface, they can transfer their energy to electrons, causing the electrons to be emitted from the surface if the photon energy exceeds the work function of the metal.

X-rays being diffracted:

X-rays can be diffracted by crystalline materials, meaning they can be scattered in a regular pattern by the atoms in a crystal lattice, which is used in X-ray crystallography to determine crystal structures.

5. Why X-rays have different properties from light even though both originate from orbital transition of electrons in excited atoms ?

ANS. X-rays and light both come from electron transitions, but their energy and wavelength are very different, which gives them different properties

- X-rays have much higher energy than visible light, so they can pass through skin and soft tissue, but light cannot.
- X-rays have very short wavelengths, which makes them behave differently like causing ionization and showing diffraction in crystals.
- Because of their energy, X-rays can remove electrons (photoelectric effect), but visible light usually cannot.

6.What is meant by Breaking Radiation?

ANS. Breaking Radiation happens when fast-moving electrons suddenly slow down or change direction near a nucleus. When this happens, they lose energy, and that energy is released as X-rays.

- A fast electron hits or passes near an atom’s nucleus.
- It slows down suddenly (like brakes in a car).
- This slowdown produces X-rays, called breaking radiations.

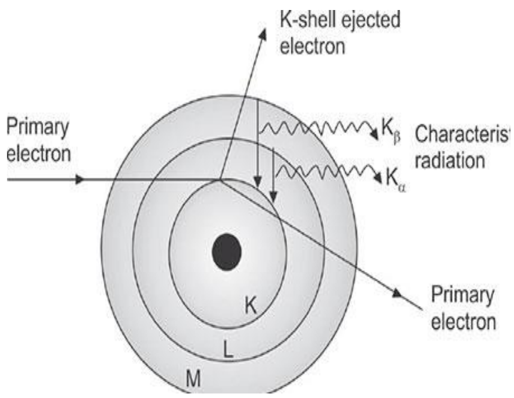
7. What are K_α Characteristic X-rays? Show with the help of diagram .

ANS.

K_α characteristic X-rays are a specific type of X-ray radiation emitted by atoms when high-energy electrons knock out inner-shell electrons (usually from the K-shell) and an electron from a higher energy level (like L-shell) falls into the vacant spot.

K_α X-rays are produced when:

- An electron is removed from the K-shell (innermost shell).
- An electron from the L-shell (next shell) falls into that vacancy.
- The energy difference between these two shells is released as K_α radiation.



Numerical Problems

1) **If potential difference of 3000 V is applied across an x-ray tube. What will be the minimum wavelength of x-rays produced, If the electrons were slowed down by the target? (Ans: 0.414 nm)**

Given Data

$V=3000V$	$e = 1.6\times10^{-19}$ C
$c= 3\times10^{8}ms^{-1}$	$h= 6.63\times10^{-34}Js$
$\lambda= ?$	

Solutions.

$$eV= hc/\lambda_{min}$$

$$\lambda_{min} = hc/eV$$

$$\lambda_{min} = (6.63\times10^{-34}Js)\times(3\times10^{8})/(1.6\times10^{-19})\times3000$$

$$\lambda_{min} = 4.13\times10^{-10}m$$

$$\lambda_{min} = 0.413\times10^{-9}m = \lambda_{min} = 0.413nm$$

2. Find the voltage across the x-ray tube through which an electron must be accelerates in order to generate the continuous x-ray of exactly 0.1 nm. (Ans: 12,400 V)

Given Data

$e = 1.6\times10^{-19}$ C $c = 3\times10^{8}ms^{-1}$

$h = 6.63\times10^{-34}Js$ $\lambda = 0.1\times10^{-9}m$

$V = ?$

Solution.

$$eV = hc/\lambda$$

$$V = hc/\lambda e$$

$$V = (6.63\times10^{-34}Js)\times(3\times10^{8})/(0.1\times10^{-9}m)\times(1.6\times10^{-19})$$

$$\mathbf{V=12400V}$$

Assignment 25.1

What will be the minimum wavelength of x-rays produced, if the electrons were slowed down by the target. The potential difference across the x-ray tube is 4000 V.

GIVEN DATA $V = 4000V$ $e = 1.6\times10^{-19}$ C

$c = 3\times10^{8}ms^{-1}$ $h = 6.63\times10^{-34}Js$

$\lambda_{min} = ?$

Solutions.

$$eV = hc/\lambda_{min}$$

$$\lambda_{min} = hc/eV$$

$$\lambda_{min} = (6.63\times10^{-34}Js)\times(3\times10^{8})/(1.6\times10^{-19})\times4000$$

$$\lambda_{min} = 3.11\times10^{-10}m$$