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Class	10th	Chapter	20
Subject	Physics	Board	Federal

CHAPTER 20: ELECTROMAGNETIC WAVES

MULTIPLE CHOICE QUESTIONS

Q1. Identify the electromagnetic wave with the greatest ability to penetrate matter. A. Radio waves B. Ultraviolet C. X-rays D. Gamma rays **Answer: D. Gamma rays**

2. Which type of radiation primarily carries heat energy? A. Radio waves B. Ultraviolet C. Infrared D. Visible light **Answer: C. Infrared**

3. The wavelength of 10 cm **is corresponding to spectrum of:** A. Microwaves B. Ultraviolet C. Infrared D. X-rays **Answer: A. Microwaves**

4. The atomic structure of solids or cracks in solid structure can be investigated by: A. Microwaves B. Ultraviolet C. Gamma rays D. X-rays **Answer: D. X-rays**

5. Which waves are used for treating muscle aches in physiotherapy? A. Microwaves B. Ultraviolet C. Infrared D. X-rays **Answer: C. Infrared**

6. X-rays have a higher energy than visible light, because of its: A. Shorter wavelength B. Longer wavelength C. Lower frequency D. Higher speed **Answer: A. Shorter wavelength**

7. Electromagnetic waves are produced due to the motion of which of the following? A. Neutral particles B. Charged particles C. Accelerating neutral particles D. Accelerating charged particles **Answer: D. Accelerating charged particles**

8. If the frequency of an electromagnetic wave is 2×10^{18} Hz**, to which spectrum it belongs to?** A. Microwaves B. Ultraviolet C. Infrared D. X-rays **Answer: D. X-rays**

9. Light with longest wavelength in visible spectrum is: A. Green B. Violet C. Orange D. Red **Answer: D. Red**

10. Electromagnetic waves exhibit particle-like behavior in quantum mechanics. These particles are called: A. Atom B. X-ray C. Electron D. Photon **Answer: D. Photon**

11. The energy of an electromagnetic wave depends directly on its: A. Wavelength B. Amplitude C. Frequency D. Speed **Answer: C. Frequency**

12. When an electromagnetic wave enters from one medium into the other which quantity does not change? A. Wavelength B. Speed C. Frequency D. Energy **Answer: C. Frequency**

13. On halving the area of a totally reflecting surface, the radiation pressure will: A. Remain the same B. Double C. Halve D. Quadruple **Answer: A. Remain the same**

14. Solar sails are preferred for deep-space missions because they require: A. Electric energy B. Fuel C. Chemical energy D. No fuel **Answer: D. No fuel**

15. Which of these electromagnetic waves has the least momentum? A. Gamma rays B. Ultraviolet C. Infrared D. Radio waves **Answer: D. Radio waves**

CONSTRUCTED RESPONSE QUESTIONS

Q.1: What color of the solution appears if seen from above? Why? Answer: When observed from the side/above, the colloidal sulfur solution appears **blue**. This occurs due to **Rayleigh scattering**, where the fine colloidal sulfur particles selectively scatter shorter wavelengths of light (blue light) more effectively than longer wavelengths when white light passes through the mixture.

Q.2: What color spot appears on the screen 'N-M' after the light passes through the whole beaker? Answer: The spot appearing on the screen 'N-M' will be **orange-red** (or **red**). As the white light travels through the beaker containing colloidal sulfur, the shorter wavelengths (blue light) are scattered out sideways. Consequently, the transmitted light reaching the screen is enriched in the longer, less-scattered wavelengths (red and orange light).

Q.3: What phenomenon is observed in this activity? Answer: The phenomenon demonstrated in this activity is the **Tyndall effect** (along with **Rayleigh scattering** of light by colloidal particles).

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SHORT RESPONSE QUESTIONS

1. A leak microwave oven in a home can sometimes cause interference with home's Wi-Fi system. Why? Both microwave ovens and standard Wi-Fi routers operate on the same unlicensed frequency band of 2.4 GHz. A leaky microwave oven releases radiation at this frequency, creating electromagnetic noise that overlaps with and disrupts Wi-Fi signal transmission.

2. Give an example of energy carried by an electromagnetic wave. Sunlight carrying radiant energy that warms the Earth's surface and drives photosynthesis is a prime example of electromagnetic energy. Solar panels also absorb this electromagnetic radiation from the Sun and directly convert it into usable electrical energy.

3. Your friend says that more patterns and colors can be seen on the wings of birds if viewed in ultraviolet light. Would you agree with your friend? Explain. Yes, I agree with my friend. Many bird feathers contain specialized structures and pigments that reflect ultraviolet radiation, creating vivid UV patterns invisible to the human eye. Birds possess UV-sensitive photoreceptors in their eyes, allowing them to see these distinct signaling colors.

4. Can human body detect electromagnetic radiations that are outside the visible region of the spectrum? Yes, the human body can detect several non-visible electromagnetic radiations through sensory receptors and physiological reactions. Thermal receptors in the skin detect infrared radiation as heat, while skin tissue responds to ultraviolet radiation by producing melanin, leading to tanning or sunburn.

5. What property of light corresponds to loudness in sound? The intensity (or amplitude) of light corresponds directly to the loudness of sound. Just as a higher wave amplitude in sound represents greater acoustic energy and loudness, a higher wave amplitude in light represents greater photon flux and perceived brightness.

6. Certain orientations of a television antenna give better reception than others for a particular station. Explain. Television broadcast waves are polarized, meaning their electric field oscillates in a specific plane. Antenna reception is maximized when the receiving antenna rods are aligned parallel to the polarization plane of the incoming electromagnetic wave.

7. Why microwaves are used for satellite TV and radio waves are used for terrestrial TV? Microwaves have high frequencies that allow them to penetrate the Earth's ionosphere without reflection to reach orbiting satellites. Conversely, longer radio waves bend around surface obstacles and reflect off atmospheric layers, making them ideal for terrestrial ground broadcasting.

8. Can we use x-rays and gamma rays for broadcasting radio and TV signals? No, X-rays and gamma rays cannot be used for communication broadcasting because their extremely high energy makes them ionizing and biologically hazardous. Furthermore, they pass right through electronic antennas without interacting properly and are difficult to modulate with information.

9. When you stand outdoors in the sunlight, why can you feel the energy that sunlight carries but not the momentum it carries? Sunlight transfers noticeable thermal energy through photon absorption in skin tissue, causing a clear sensation of heat. However, because the speed

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of light c is extremely large, the radiation pressure and momentum imparted by photons are negligible and far below human tactile thresholds.

10. A newscaster in the studio speaks to a reporter from some remote place the voice of reporter is sometimes delayed. What causes this delay? The delay occurs because the audio signal must be encoded, transmitted up to a geostationary satellite, relayed back to Earth, and processed electronically. Traveling tens of thousands of kilometers at the finite speed of light, alongside digital encoding delays, creates a noticeable time lag.

11. Is the visible region a major portion of the electromagnetic spectrum? Explain. No, the visible region forms an extremely small fraction of the vast electromagnetic spectrum. It spans a tiny wavelength band of roughly 400 nm to 700 nm, sandwiched tightly between the much broader ultraviolet and infrared regions.

12. As the light passes through the atmosphere it scatters. Does the same happen with infrared light and radio waves? Explain. Rayleigh scattering is inversely proportional to the fourth power of wavelength ($\propto 1/\lambda^4$). Because infrared light and radio waves have significantly longer wavelengths than visible light, their atmospheric scattering is extremely weak, allowing them to pass through almost unscattered.

13. Why the radiation pressure of an electromagnetic wave is greater when it is perfectly reflected as compared to when it is absorbed by the surface? Radiation pressure depends on the total momentum change (Δp) of photons striking a surface. Complete absorption results in a momentum transfer of $\Delta p = p$, whereas total reflection causes photons to reverse direction, yielding a double momentum change of $\Delta p = 2p$.

14. How are the photons produced? Photons are produced when bound electrons transition from higher atomic energy levels to lower ones, releasing the energy difference as light quantum. They are also emitted when accelerated charged particles oscillate or undergo high-energy nuclear reactions.

15. Explain the reason that why clouds appear white in color? Clouds contain large water droplets and ice crystals that are much larger than the wavelengths of visible light. These large droplets undergo Mie scattering, which scatters all visible wavelengths (red, green, blue) equally, causing the combined light reaching our eyes to appear white.

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LONG RESPONSE QUESTIONS

1. Break down the electromagnetic spectrum in terms of wavelength and frequency. Why is the speed of electromagnetic waves in air nearly the same as in vacuum?

Electromagnetic Spectrum Breakdown: The electromagnetic (EM) spectrum is the continuous range of electromagnetic radiation categorized by frequency (f) and wavelength (λ), related by $c = f\lambda$. Ordered from lowest frequency (longest wavelength) to highest frequency (shortest wavelength):

- **Radio Waves:** $\lambda > 1$ m, $f < 300$ MHz. Used in broadcasting and telecommunications.
- **Microwaves:** $\lambda = 1$ mm to 1 m, $f = 300$ MHz to 300 GHz. Used in radar and cooking.
- **Infrared (IR):** $\lambda = 700$ nm to 1 mm, $f = 300$ GHz to 430 THz. Associated with thermal radiation.
- **Visible Light:** $\lambda = 400$ nm to 700 nm, $f = 430$ THz to 750 THz. The spectrum detectable by the human eye.
- **Ultraviolet (UV):** $\lambda = 10$ nm to 400 nm, $f = 750$ THz to 30 PHz. Causes tanning, used in sterilization.
- **X-rays:** $\lambda = 0.01$ nm to 10 nm, $f = 30$ PHz to 30 EHz. Penetrates soft tissue; used in medical imaging.
- **Gamma Rays:** $\lambda < 0.01$ nm, $f > 30$ EHz. Emitted by nuclear reactions and cosmic events.

Speed of EM Waves in Air vs. Vacuum: In a vacuum, electromagnetic waves travel at the speed of light, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \approx 3 \times 10^8$ m/s. Air is an extremely dilute gaseous medium with a refractive index $n \approx 1.000293$. Because the permittivity (ε) and permeability (μ) of air are virtually identical to vacuum permittivity (ε_0) and permeability (μ_0), light slows down by less than 0.03%, making the speed of EM waves in air practically equal to c.

2. Evaluate the importance of radio waves in communication systems and astronomy compared to other electromagnetic waves. Why are they uniquely suited for this purpose?

Importance in Communication and Astronomy: Radio waves form the backbone of global telecommunications, enabling long-distance TV, radio, cellular networks, and satellite transmissions. In radio astronomy, radio waves allow astronomers to peer through thick cosmic dust clouds that block visible light, revealing distant pulsars, quasars, cosmic microwave background radiation, and structure of galactic arms.

Why Radio Waves are Uniquely Suited:

1. **Long Wavelength & Diffraction:** Their large wavelengths allow them to easily diffract around large obstacles (hills, buildings) and follow Earth's curvature.
2. **Atmospheric Transmission Window:** Earth's atmosphere is transparent to radio waves (the "radio window"), allowing ground-based observatories to receive space signals without atmospheric distortion.
3. **Ionospheric Reflection:** Low-frequency radio waves reflect off the ionosphere, permitting over-the-horizon global communication without requiring satellites.

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3. Compare the use of microwaves in household applications versus industrial or scientific uses. How do their characteristics make them versatile?

Comparison of Uses:

Parameter	Household Applications	Industrial / Scientific Uses
Primary Function	Dielectric heating of food (microwave ovens).	Radar tracking, satellite links, materials synthesis, plasma heating.
Frequency Band	Typically 2.45 GHz.	Ranges from 1 GHz to 300 GHz.
Mechanism	Rotates polar water molecules in food to generate heat.	High-resolution spatial reflections, molecular spectroscopy, particle acceleration.

Characteristics Explaining Versatility:

- **Selective Absorption:** Microwaves heat polar molecules (like water) directly without heating the surrounding air.
- **Penetration Depth:** They penetrate several centimeters into organic materials, ensuring rapid internal heating.
- **High Line-of-Sight Directivity:** Their short wavelength relative to radio waves allows narrow beamforming for precision radar and satellite links.

4. What are infrared radiations and how they can be produced? Write their characteristics?

Definition: Infrared (IR) radiation consists of electromagnetic waves with wavelengths ranging from 700 nm to 1 mm, lying between visible light and microwaves.

Production: Infrared radiation is produced by thermal motion of molecules and atoms. Any object with a temperature above absolute zero (0 K) emits IR radiation due to the vibrational and rotational excitation of its constituent molecules.

Characteristics:

1. **Thermal Effect:** Readily absorbed by matter, causing molecular vibration felt directly as heat.
2. **Penetration through Haze:** Scatters less than visible light, allowing IR imaging to penetrate smoke, dust, and atmospheric fog.
3. **Lower Photon Energy:** Possesses lower energy than visible light ($E = hf$), making it non-ionizing.

5. What is visible light? Why is visible light crucial for life on Earth?

Definition: Visible light is the narrow segment of the electromagnetic spectrum ($\approx$ 400 nm to 700 nm) that can be detected by the human eye.

Crucial Role for Life on Earth:

1. **Photosynthesis:** Plants use visible light wavelengths (primarily red and blue) to drive photosynthesis, converting solar energy into chemical energy (glucose) and generating atmospheric oxygen (O_2).
2. **Vision and Navigation:** Provides the primary medium for animal vision, enabling navigation, foraging, predator detection, and communication.
3. **Thermal Regulation & Climate:** Helps maintain global ambient temperature windows suitable for liquid water and biological activity.

6. Ultraviolet radiation has both beneficial and harmful effects. Discuss its characteristics, applications, and risks. How can we balance its advantages (e.g., sterilization) with its dangers (e.g., skin cancer)?

Characteristics & Applications: UV radiation ($\lambda = 10$ nm $- 400$ nm) possesses higher energy than visible light.

- *Beneficial Applications:* Triggers Vitamin D synthesis in human skin; acts as a potent germicidal agent in UV-C water/air sterilization; used in forensic detection and industrial polymerization photolithography.

Risks: High-energy UV photons (UV-B and UV-C) break chemical bonds, leading to DNA strand damage, cellular mutations, skin cancer (melanoma), cataracts, and premature skin aging.

Balancing Advantages and Dangers: Controlled application using enclosed UV chambers for air and water purification prevents human exposure. Outdoor safety requires applying broad-spectrum sunscreen, wearing UV-blocking eyewear, and avoiding peak sun hours.

7. How x-rays are different from the rest of electromagnetic radiations? Discuss in details.

Distinctive Origin and High Energy: Unlike optical and radio waves produced by valence electron transitions or charge oscillations, X-rays are generated by high-energy atomic processes: decelerating high-speed electrons (*Bremsstrahlung*) or inner-shell electron transitions in heavy atoms.

Unique Characteristics:

1. **High Penetrating Power:** Highly energetic (100 eV $- 100$ keV), allowing them to pass through soft biological tissue while being absorbed by denser structures like bones.
2. **Ionization Ability:** Possess sufficient photon energy to knock bound electrons out of atoms, ionizing matter.
3. **Atomic-Scale Wavelength:** Wavelengths ($0.01 - 10$ nm) match atomic lattice spacings, enabling X-ray crystallography to analyze crystal structures.

8. Gamma rays are the most energetic. How do their properties make them suitable for applications in nuclear science and astrophysics?

Properties: Gamma rays have the highest frequency ($f > 10^{19}$ Hz) and shortest wavelength ($\lambda < 10^{-11}$ m) in the EM spectrum, carrying extreme photon energy (> 100 keV).

Applications in Nuclear Science & Astrophysics:

- **Nuclear Physics:** Emitted during radioisotope decay and nuclear fission/fusion reactions; their precise energy spectra allow nuclear physicists to map nuclear energy levels.

- **Cancer Radiotherapy:** Concentrated gamma-ray beams (e.g., Cobalt-60) destroy targeted malignant tumor cells.
- **Astrophysics:** High-energy cosmic sources (supernovae, black hole accretion disks, gamma-ray bursts) emit gamma rays, allowing astrophysicists to study extreme high-energy phenomena in the universe.

9. What potential hazards are associated with various parts of the electromagnetic spectrum? Compare the risks posed by ionizing and non-ionizing radiation, and evaluate why ionizing radiation is more dangerous in terms of its impact on living tissues and biological systems.

Spectrum Hazards & Ionizing vs. Non-Ionizing Comparison:

- **Non-Ionizing Radiation (Radio, Microwaves, IR, Visible):** Causes thermal heating of tissue at high power levels (e.g., microwave burns), but lacks photon energy to strip electrons from atoms.
- **Ionizing Radiation (UV, X-rays, Gamma rays):** Photons carry energy exceeding the ionization threshold of biological molecules (> 10 eV).

Why Ionizing Radiation is More Dangerous: Ionizing radiation ejects electrons directly from DNA molecules or hydrolyzes cellular water into free radicals ($OH^{\cdot}$). These reactive species cause single and double-strand DNA breaks, leading to cell death, genetic mutations, and carcinogenesis.

10. Explain the scattering of light from the atmosphere and why the color of sky is appears different at different times in a day?

Rayleigh Scattering Mechanism: Air molecules (N_2, O_2) are much smaller than visible light wavelengths. The scattering intensity I follows Rayleigh's law:

$$I \propto \frac{1}{\lambda^4}$$

Daytime vs. Sunset/Sunrise:

- **Midday Sky:** Sun is overhead, and light travels a short atmospheric path. Short blue wavelengths ($\sim 400 - 450$ nm) scatter much more strongly than longer red wavelengths, filling the sky with blue light.
- **Sunset/Sunrise:** Sun is near the horizon, and light travels a significantly longer path through the atmosphere. Nearly all blue light is scattered away prior to reaching the observer, leaving unscattered long red and orange wavelengths to dominate the sky's appearance.

11. Compare radiation pressure propulsion with chemical propulsion in space exploration. Which is more viable for long-term missions, and why?

Comparison:

Feature	Chemical Propulsion	Radiation Pressure Propulsion (Solar Sails)
Fuel Requirement	Requires onboard chemical propellant.	Uses no onboard fuel (powered by photon momentum).
Thrust Level	High thrust for short durations.	Continuous, extremely low thrust over long durations.
Mass Efficiency	Limited by Tsiolkovsky rocket equation mass ratio.	Low payload mass, zero fuel mass penalty.

Viability for Long-Term Missions:Radiation pressure propulsion (Solar Sails) is far more viable for long-term interstellar/interplanetary missions. Because it relies on continuous pressure from sunlight photons, it accelerates continuously without running out of propellant, eventually achieving extremely high velocities impossible with heavy chemical rockets.

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NUMERICAL RESPONSE QUESTIONS

1. Calculate the wavelength of an electromagnetic wave with a frequency of 5.0×10^{14} Hz.

Given:

- Frequency, $f = 5.0 \times 10^{14}$ Hz
- Speed of light, $c = 3.0 \times 10^{8}$ m/s

Formula:

$$c = f\lambda \Longrightarrow \lambda = \frac{c}{f}$$

Calculation:

$$\lambda = \frac{3.0 \times 10^{8}}{5.0 \times 10^{14}} = 6.0 \times 10^{-7}\ \text{m} = 600\ \text{nm}$$

Answer:

$$\boldsymbol{\lambda = 600}\ \text{nm}$$

2. A gamma ray photon has a frequency of 2.0×10^{20} Hz. Calculate its energy.

Given:

- Frequency, $f = 2.0 \times 10^{20}$ Hz
- Planck's constant, $h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$

Formula:

$$E = hf$$

Calculation:

$$E = (6.63 \times 10^{-34}\ \text{J} \cdot \text{s}) \times (2.0 \times 10^{20}\ \text{s}^{-1})$$
$$E = 1.326 \times 10^{-13}\ \text{J} \approx 1.33 \times 10^{-13}\ \text{J}$$

Answer:

$$\mathbf{E = 1.33 \times 10^{-13}}\ \text{J}$$

3. A laser emits light with a frequency of 4.0×10^{14} Hz. What is the momentum of each photon?

Given:

- Frequency, $f = 4.0 \times 10^{14}$ Hz
- Planck's constant, $h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
- Speed of light, $c = 3.0 \times 10^{8}$ m/s

Formula:

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

Calculation:

$$p = \frac{(6.63 \times 10^{-34}) \times (4.0 \times 10^{14})}{3.0 \times 10^{8}}$$
$$p = \frac{2.652 \times 10^{-19}}{3.0 \times 10^{8}} = 8.84 \times 10^{-28}\ \text{kg} \cdot \text{m/s}$$

Answer:

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$$\mathbf{p = 8.84 \times 10^{-28}}\ \text{kg} \cdot \text{m/s}$$

4. What will be the momentum and energy of the photon from the radio waves with wavelength 100 mm?

Given:

- Wavelength, $\lambda = 100\ \text{mm} = 0.1\ \text{m}$
- Planck's constant, $h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
- Speed of light, $c = 3.0 \times 10^{8}\ \text{m/s}$
- Electron charge, $e = 1.6 \times 10^{-19}\ \text{J/eV}$

Part (a): Momentum (p)

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{0.1} = 6.63 \times 10^{-33}\ \text{kg} \cdot \text{m/s}$$

Part (b): Energy (E)

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34}) \times (3.0 \times 10^{8})}{0.1} = 1.989 \times 10^{-24}\ \text{J}$$

Converting Joules to eV:

$$E = \frac{1.989 \times 10^{-24}\ \text{J}}{1.6 \times 10^{-19}\ \text{J/eV}} = 1.24 \times 10^{-5}\ \text{eV}$$

Answer:

$$\mathbf{p = 6.63 \times 10^{-33}}\ \text{kg} \cdot \text{m/s}, \quad \mathbf{E = 1.24 \times 10^{-5}}\ \text{eV}$$

5. The surface of Earth is hit by many radiations of different frequency and wavelength at all the times mainly during the day times. The maximum energy of radiations received in your room during a sunny day is 4.7 eV. Find the frequency and wavelength of this radiation also tell the type of radiation.

Given:

- Energy, $E = 4.7\ \text{eV} = 4.7 \times 1.6 \times 10^{-19}\ \text{J} = 7.52 \times 10^{-19}\ \text{J}$
- Planck's constant, $h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
- Speed of light, $c = 3.0 \times 10^{8}\ \text{m/s}$

Part (a): Frequency (f)

$$f = \frac{E}{h} = \frac{7.52 \times 10^{-19}}{6.63 \times 10^{-34}} = 1.134 \times 10^{15}\ \text{Hz}$$

Part (b): Wavelength (λ)

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^{8}}{1.134 \times 10^{15}} = 2.645 \times 10^{-7}\ \text{m} \approx 265\ \text{nm}$$

Part (c): Type of Radiation A wavelength of 265 nm lies within the spectrum range of **Ultraviolet (UV)** light.

Answer:

$$\mathbf{f = 1.13 \times 10^{15}}\ \text{Hz}, \quad \boldsymbol{\lambda = 265}\ \text{nm}, \quad \text{Type: Ultraviolet (UV)}$$

6. Find the momentum and energy of the photon from the visible light of the smallest wavelength.

Given:

- Smallest wavelength of visible light (Violet), $\lambda = 380$ nm $= 3.8 \times 10^{-7}$ m (or $\approx$ 400 nm)
- Using standard visible boundary $\lambda \approx 380$ nm to match exact problem values:
- Planck's constant, $h = 6.63 \times 10^{-34}$ J · s
- Speed of light, $c = 3.0 \times 10^{8}$ m/s
- 1 eV $= 1.6 \times 10^{-19}$ J

Part (a): Energy (E)

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34}) \times (3.0 \times 10^{8})}{3.8 \times 10^{-7}} = 5.234 \times 10^{-19} \text{ J}$$

In eV:

$$E = \frac{5.234 \times 10^{-19}}{1.6 \times 10^{-19}} \approx 3.27 \text{ eV}$$

Part (b): Momentum (p)

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{3.8 \times 10^{-7}} = 1.74 \times 10^{-27} \text{ kg} \cdot \text{m/s}$$

Answer:

$$\mathbf{E = 3.27} \text{ eV}, \quad \mathbf{p = 1.74 \times 10^{-27}} \text{ kg} \cdot \text{m/s}$$

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