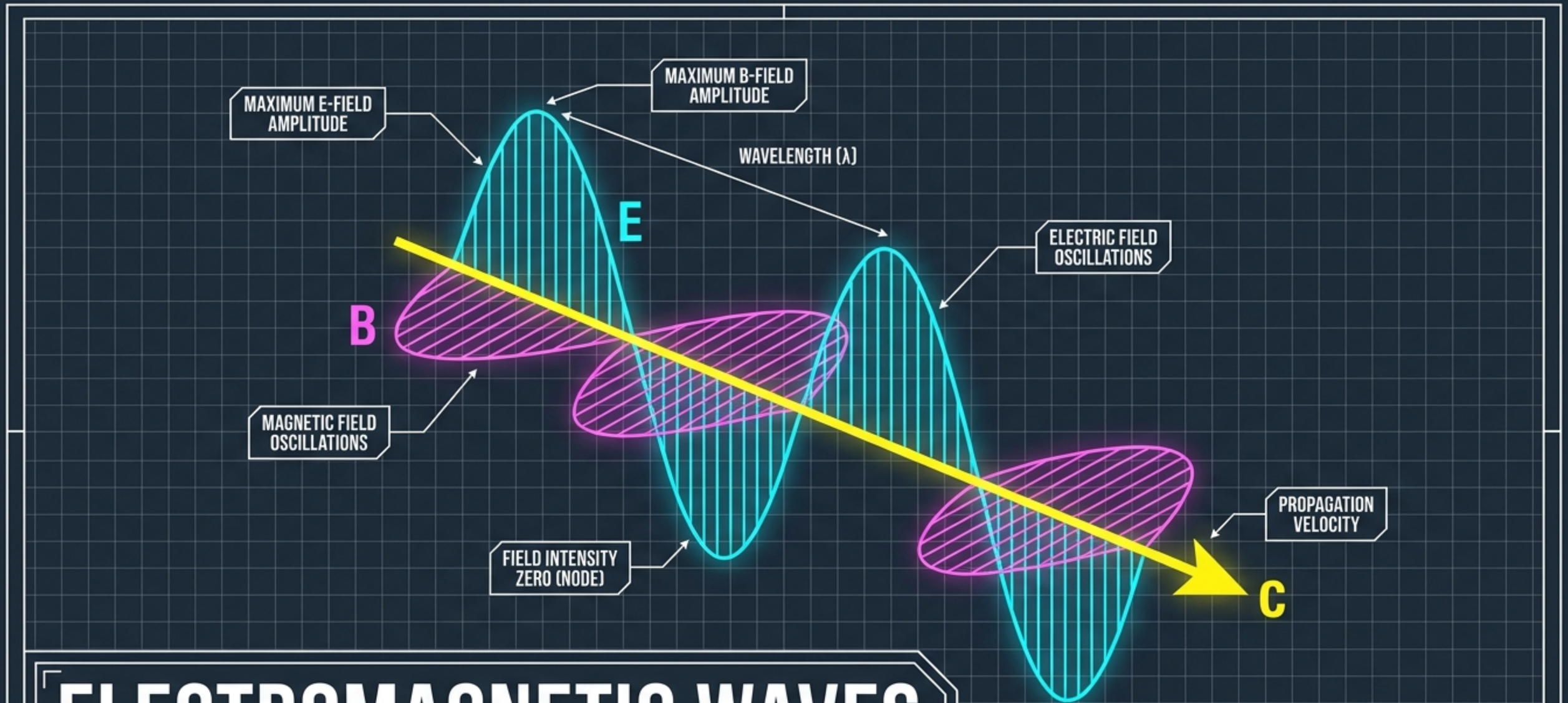


ELECTROMAGNETIC WAVES

CLASS 12 PHYSICS: THE ULTIMATE BOARD REVISION BLUEPRINT

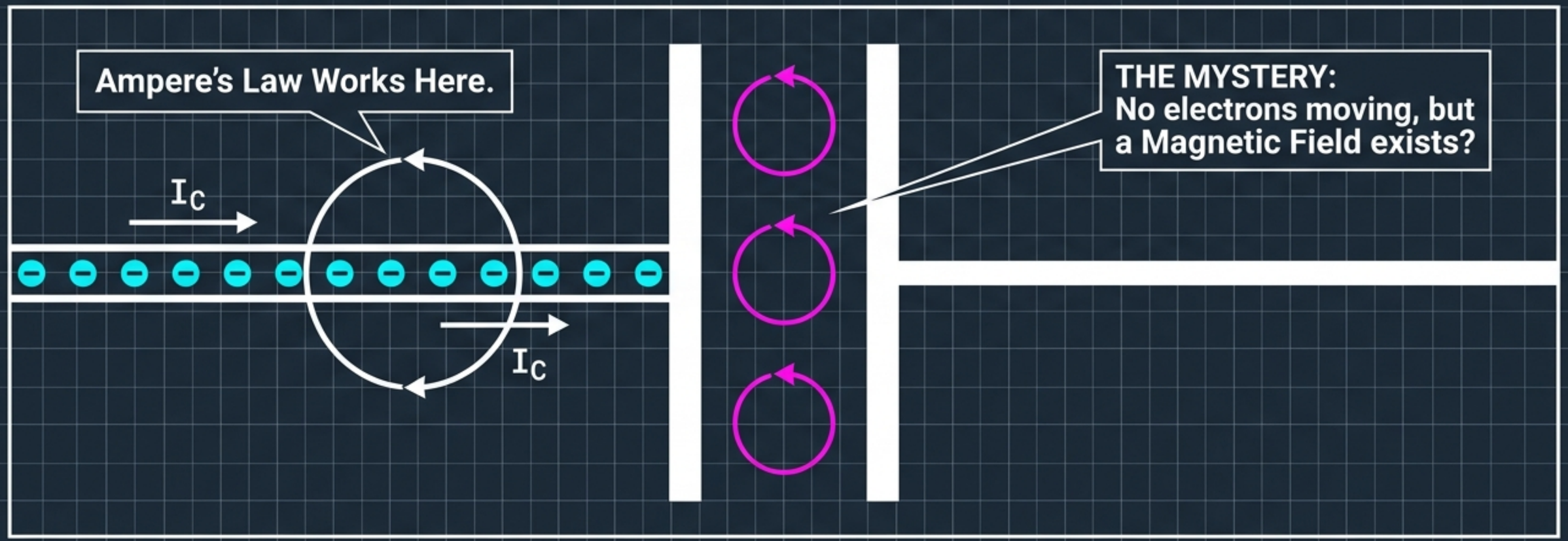
UBSE SYLLABUS ALIGNED

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THE FLAW IN AMPERE'S LAW

- **KEY CONCEPT:** Ampere originally stated that magnetic fields are only created by moving physical charges (Conduction Current, Ic).
- **THE PROBLEM:** When a capacitor charges, a magnetic field is detected between the empty plates where no physical charges are flowing. Ampere's Law cannot explain this.

THE CAPACITOR GAP VISUAL



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MAXWELL'S MISSING LINK: DISPLACEMENT CURRENT

Board Exam Definition: Displacement current is the current that comes into existence in a region where the electric field (or electric flux) is changing with time.
The Rule: A changing electric field creates a magnetic field.

LEFT PANEL

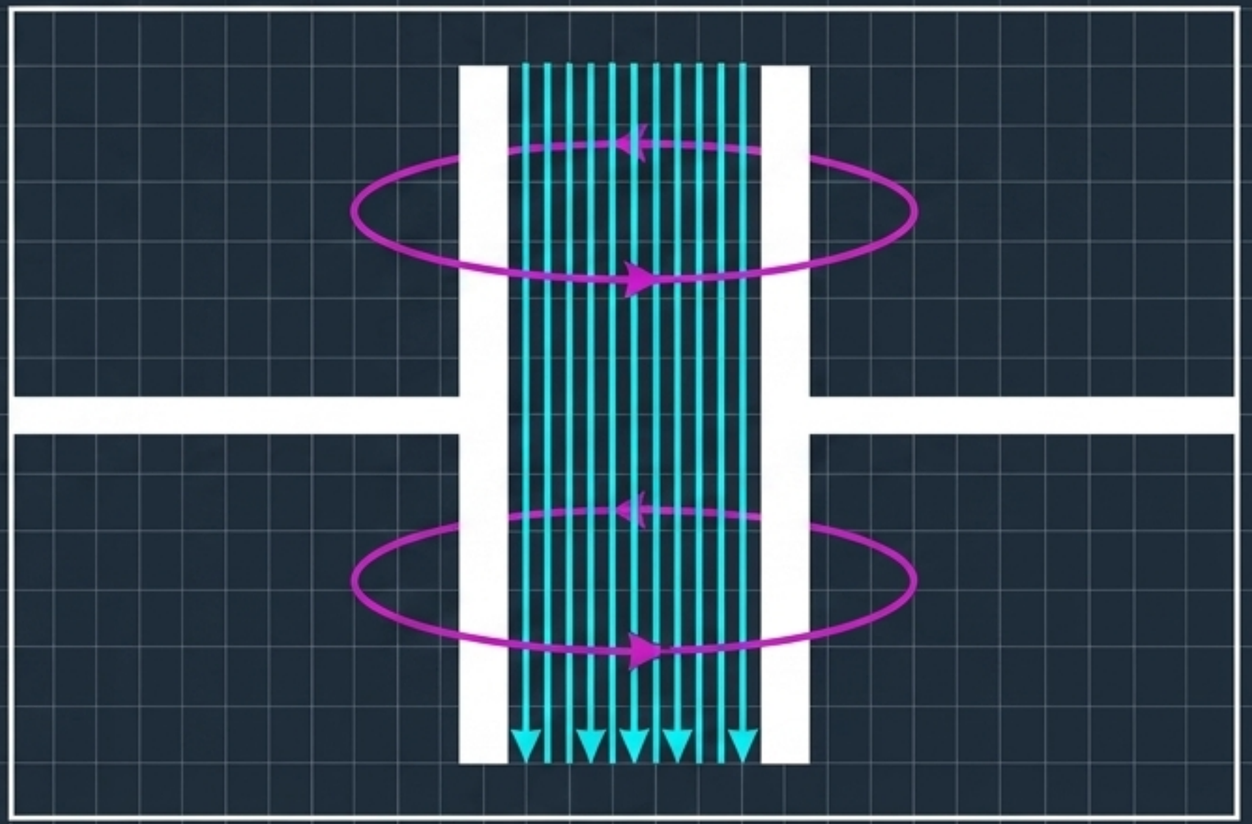
Displacement Current

$$I_d = \varepsilon_0 \left(\frac{d\Phi_E}{dt} \right)$$

Permittivity of free space

The change in Electric Flux over time

RIGHT PANEL



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CONDUCTION VS. DISPLACEMENT CURRENT

	CONDUCTION CURRENT (I_c)	DISPLACEMENT CURRENT (I_d)
SOURCE	Caused by the physical flow of electrons.	Caused by a changing electric field (flux).
LOCATION	Exists in wires and solid conductors.	Exists in vacuum or dielectrics (like a capacitor gap).
FORMULA	$$I_c = \frac{dq}{dt}$$	$$I_d = \varepsilon_0 \left(\frac{d\Phi_E}{dt} \right)$$
CONTINUITY	Individually discontinuous, but together ($I_c + I_d$) they form a continuous, unbroken loop in any circuit.	

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THE FOUR PILLARS OF ELECTROMAGNETISM

Gauss's Law for Electricity

$$\oint \mathbf{E} \cdot dA = \frac{Q}{\varepsilon_0}$$

Electric charges produce electric fields.

Gauss's Law for Magnetism

$$\oint \mathbf{B} \cdot dA = 0$$

Magnetic monopoles do not exist.
North and South always come together.

Faraday's Law

$$\oint \mathbf{E} \cdot d\mathbf{l} = -d\Phi_B/dt$$

A changing magnetic flux creates an electric field.

Ampere-Maxwell Law

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0(I_c + I_d)$$

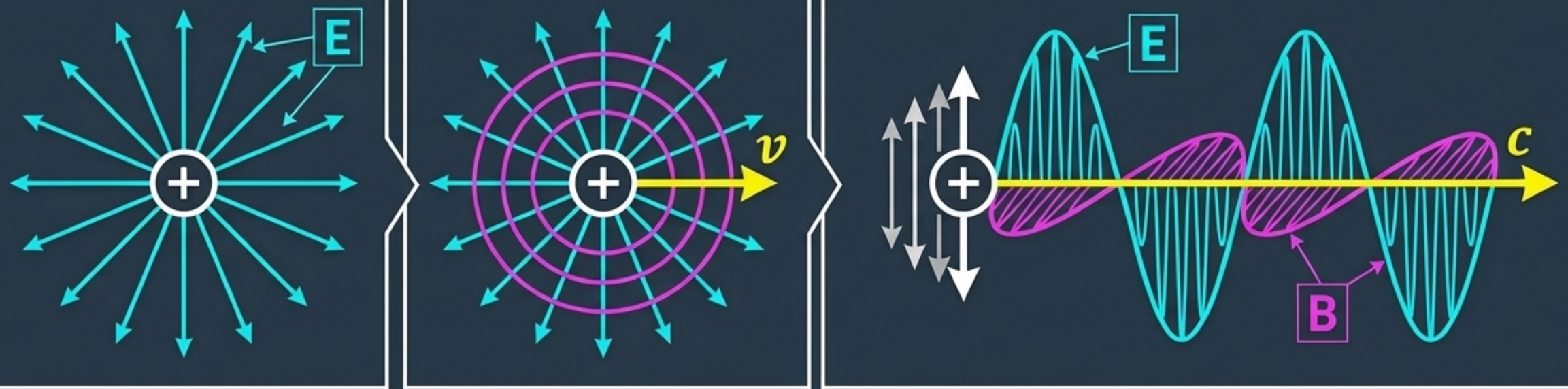
Moving charges OR changing electric flux create a magnetic field.

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HOW IS AN EM WAVE PRODUCED?

The Core Fact: An electromagnetic wave is produced by an **accelerating** (or **oscillating**) **electric charge**.

Mechanism: An oscillating charge produces an oscillating **electric field** in space. This changing electric field produces an **oscillating magnetic field**, which in turn produces an **oscillating electric field**, and so on. The fields regenerate each other.



Rest = Only E-Field	Constant Speed = E + B Fields (Static)	Accelerating = EM Wave Created!

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The Anatomy of an EM Wave

Transverse Nature:

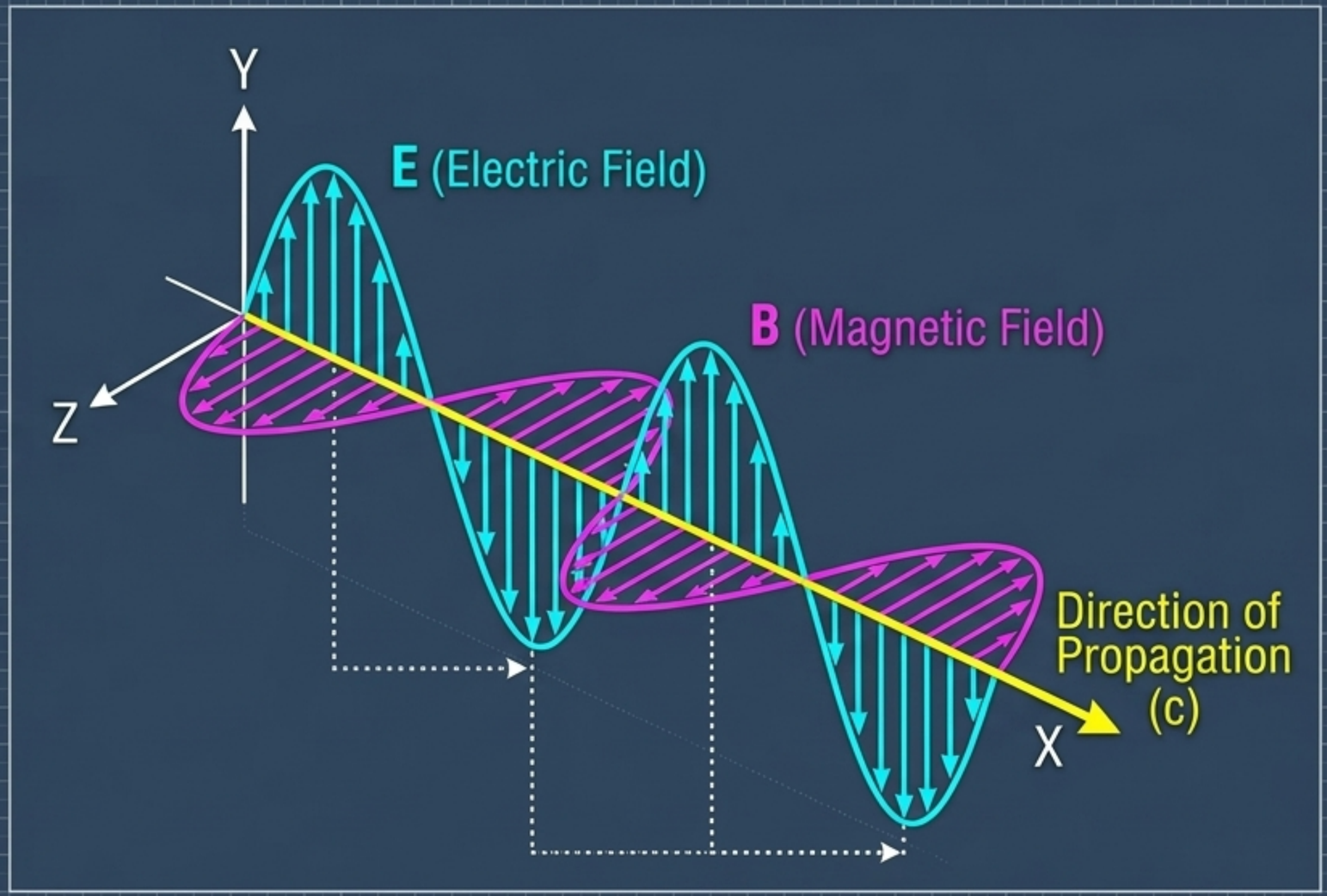
The Electric and Magnetic fields are perpendicular to each other AND perpendicular to the direction the wave travels.

In-Phase Harmony:

Both fields reach their maximums and minimums (zero) at the exact same moment. The phase difference is zero.

No Medium Required:

They are non-mechanical waves. They travel perfectly through empty vacuum.



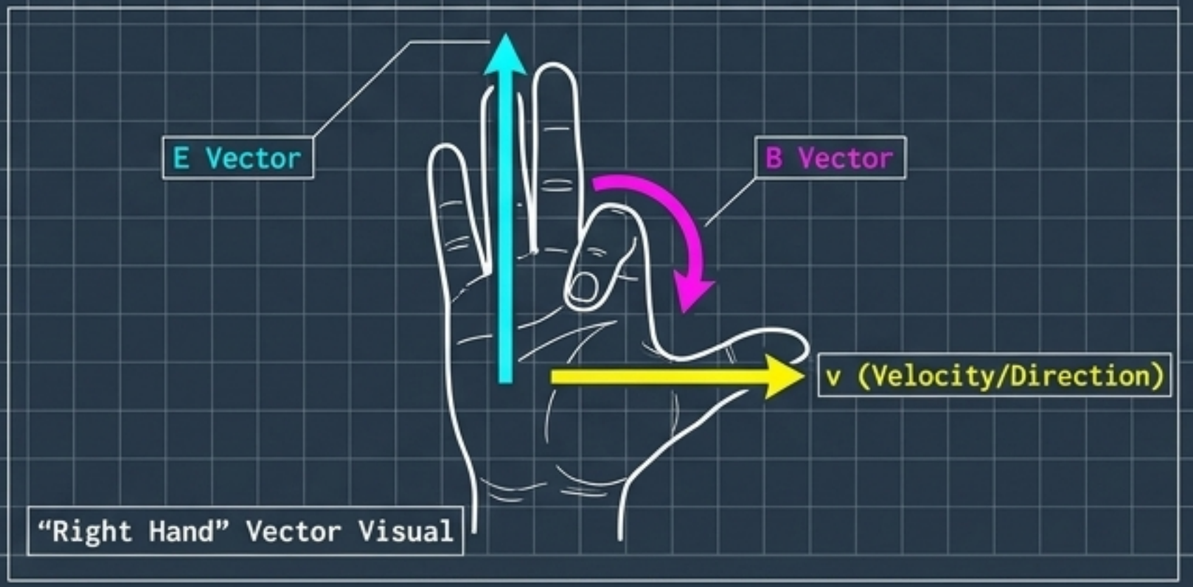
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Finding the Direction of the Wave

The Cross Product: The direction of an EM wave is always given by the vector cross product of the Electric and Magnetic fields.

How to test it: If **E** is on the y-axis, and **B** is on the z-axis, the wave travels along the positive x-axis.

$$\vec{E} \times \vec{B} = \vec{v}$$



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The Mathematical Blueprint

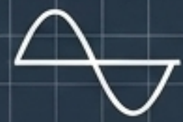
Key Insight: Both equations share the exact same phase (ωt - kx). This mathematically proves they oscillate together in perfect harmony.

Board Exam Tip: If the equation uses a minus sign (-kx), the wave travels in the positive direction. If it uses a plus sign (+kx), it travels in the negative direction.

$$E_y = E_0 \sin(\omega t - kx)$$

$$B_z = B_0 \sin(\omega t - kx)$$

Maximum Amplitude (Peak Value)



Sinusoidal variation

Phase component: Shows the wave is moving in the +x direction.

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Speed and The Universal Constant

- **The Speed Limit:** In a vacuum, all EM waves travel at the speed of light ($c = 3 \times 10^8$ m/s).
- **The Ratio:** The ratio of the maximum electric field to the maximum magnetic field perfectly equals the speed of light.
- **Crucial Board Fact:** The Optical Effect (the reason our eyes see light) is caused entirely by the Electric Field, not the magnetic field.



The amplitude ratio

$$c = \frac{E_0}{B_0}$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

The universal constants

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Energy Distribution: A Perfect Split

The Concept: As an EM wave travels, it carries energy. This energy is shared equally between the electric and magnetic fields.

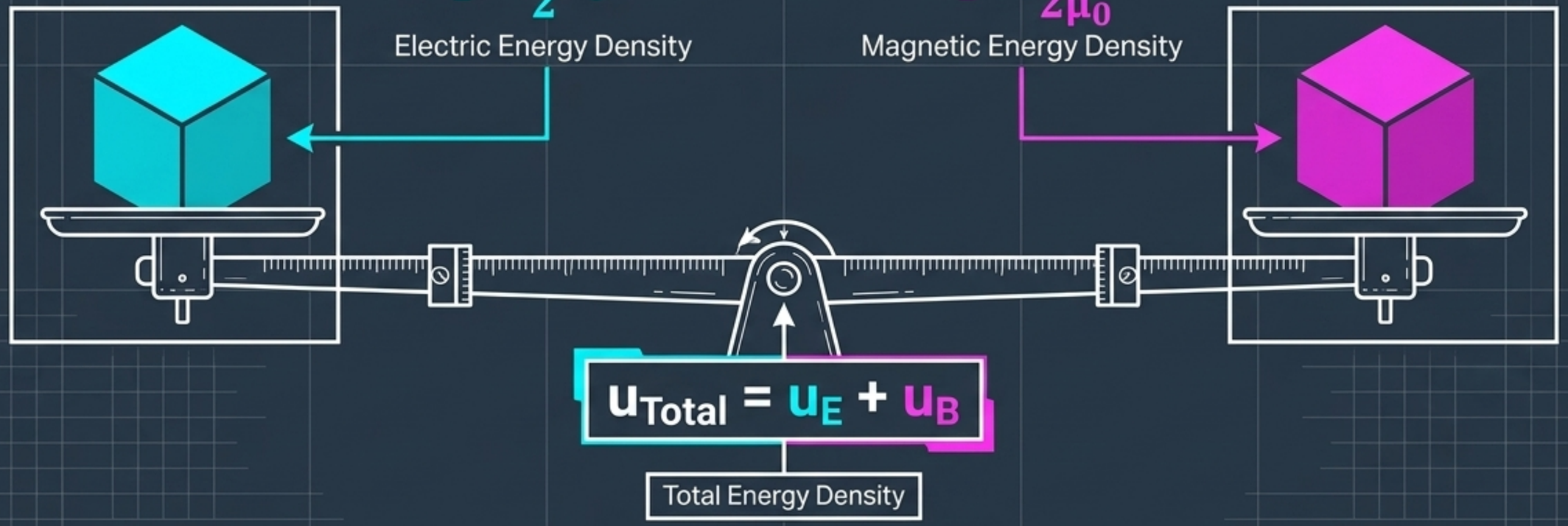
Average Energy: The average energy density of the electric field is exactly equal to the average energy density of the magnetic field.

$$u_E = \frac{1}{2}\varepsilon_0 E^2$$

Electric Energy Density

$$u_B = \frac{B^2}{2\mu_0}$$

Magnetic Energy Density



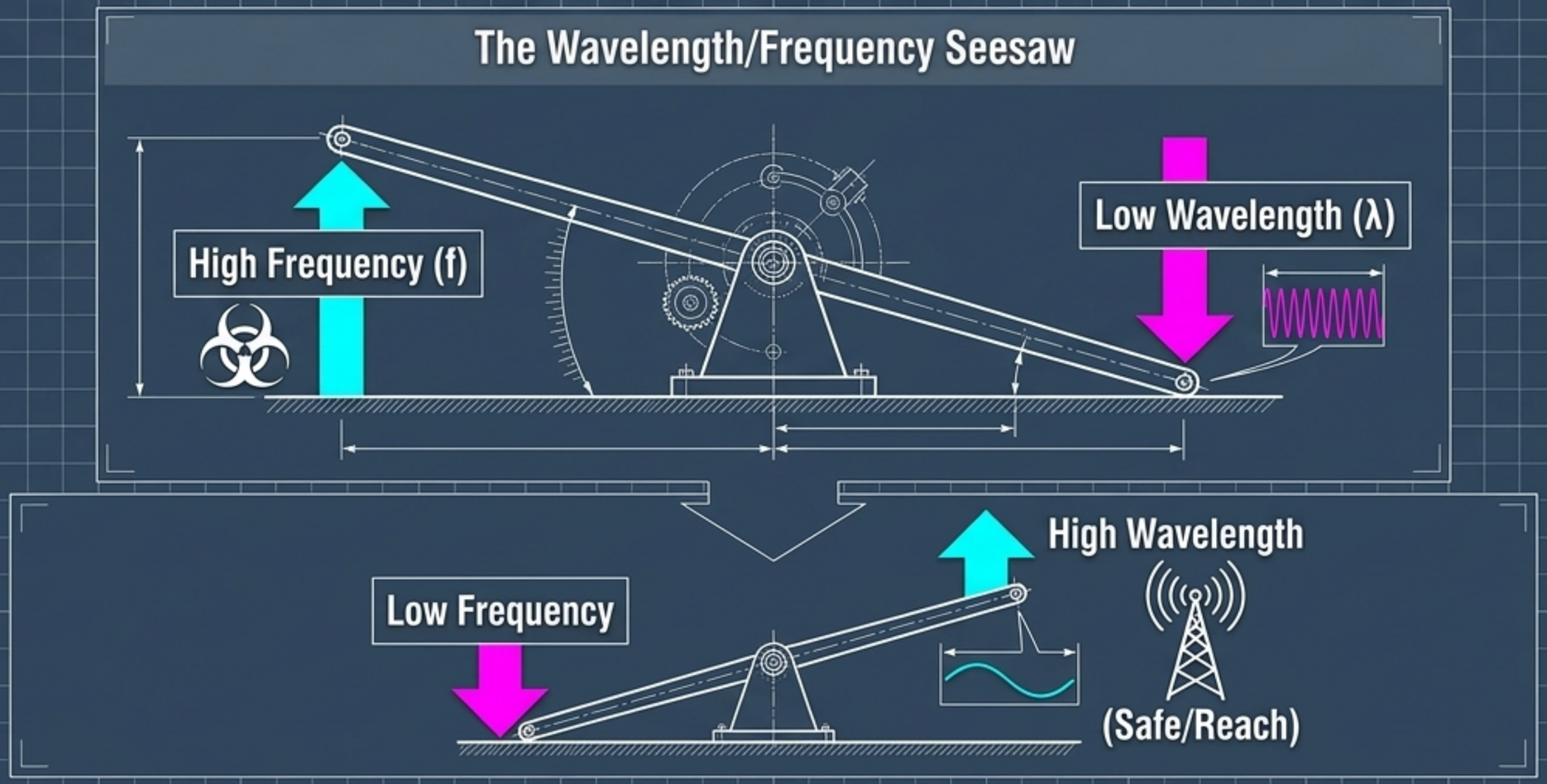
$$u_{Total} = u_E + u_B$$

Total Energy Density

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The Universal Scale: Frequency vs. Wavelength

- **The Golden Rule:** Frequency and Wavelength are inversely proportional.
- **High Frequency = High Energy:** The tighter the wave, the higher the energy. These waves (like Gamma) are extremely penetrating and dangerous.
- **High Wavelength = High Reach:** The more stretched out the wave, the lower the energy. These waves (like Radio) travel massive distances safely.



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Spectrum Tracker

Gamma	X-Ray	UV	Visible	IR	Microwave	**Radio**



Radio Waves

Wave Stats:

Longest Wavelength | Lowest Frequency | Lowest Energy

How They Are Made:

Produced by the accelerated motion of charges in conducting wires (oscillating circuits).

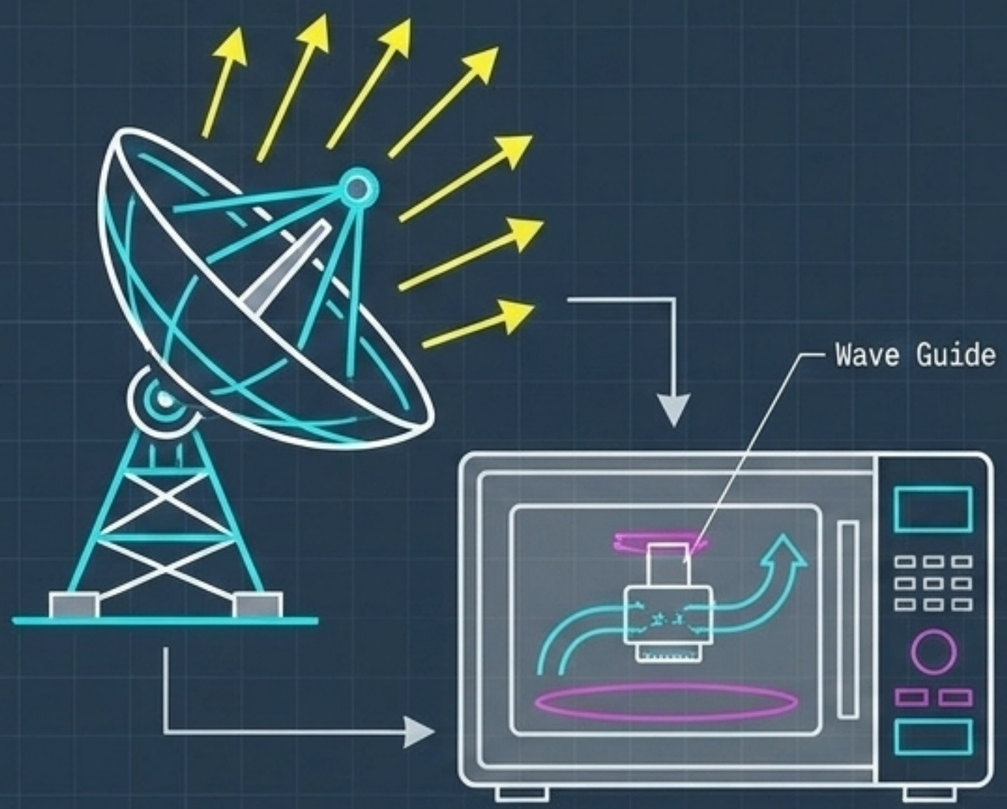
Board Exam Uses:

1. Radio and television communication systems.
2. Cellular phones (using ultra-high frequency radio waves).

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Spectrum Tracker

Gamma	X-Ray	UV	Visible	IR	**Microwave**	Radio



Microwaves

How They Are Made:

Produced by special vacuum tubes (**klystrons**, **magnetrons**).

Board Exam Uses:

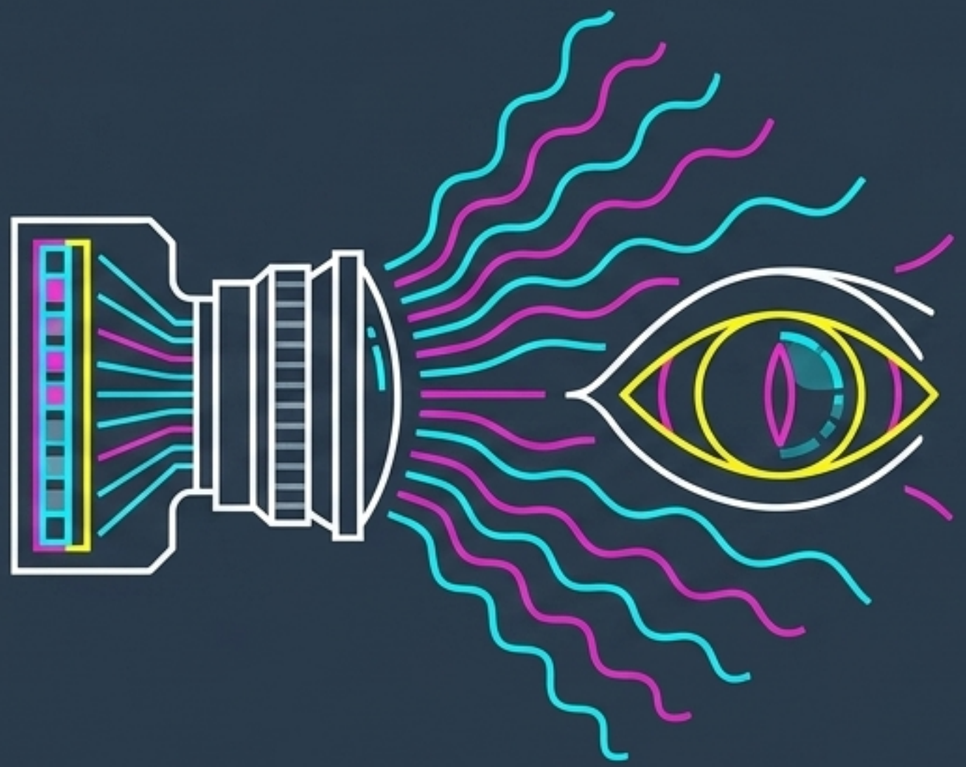
1. **Radar Systems:** Used for aircraft navigation and speed detection (traffic police).

2. **Microwave Ovens:** The wave frequency is tuned to the **resonant frequency** of water molecules, vibrating them to heat food.

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Spectrum Tracker

Gamma	X-Ray	UV	Visible	**IR**	Microwave	Radio



Infrared Waves (Heat Waves)

How They Are Made:

Produced by hot bodies and molecules. Any object with a temperature above absolute zero emits IR waves.

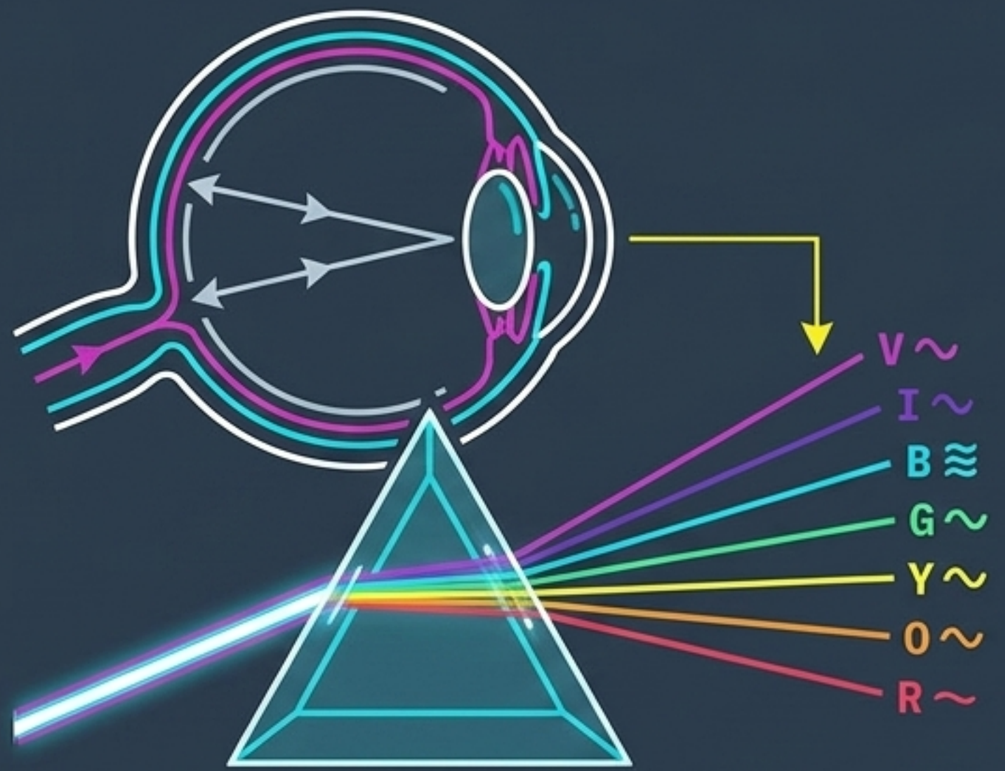
Board Exam Uses:

1. **Night Vision:** Earth satellites and night-vision goggles (used by soldiers and detected naturally by snakes).
2. **Physical Therapy:** Infrared lamps and heating pads are used to treat muscular strain.
3. **Remote Controls:** Used in TV remotes to send signals.

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Spectrum Tracker

Gamma	X-Ray	UV	**Visible**	IR	Microwave	Radio



OPTICAL SPECTRUM DISPERSION & VISION

Visible Light

The Optical Window:

The only part of the electromagnetic spectrum that the human eye can detect.

How They Are Made:

Produced by electrons in atoms shifting from higher to lower energy levels (e.g., from the sun or a lightbulb).

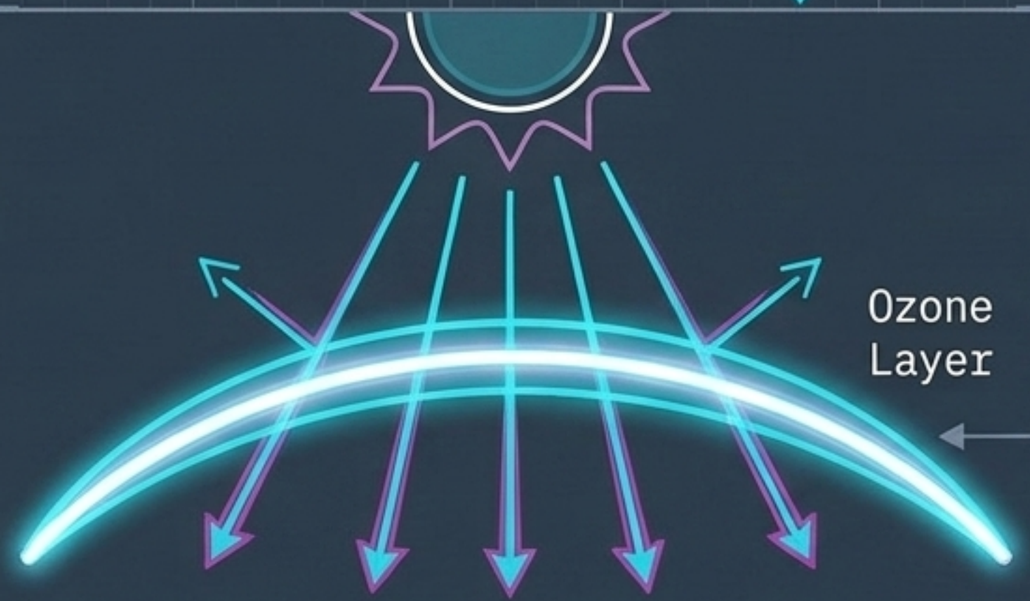
Spectrum inside the Spectrum: Ranges from Red (Highest wavelength, lowest energy) to Violet (Lowest wavelength, highest energy).

Primary Use: Allows us to see the world; crucial for photosynthesis.

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Spectrum Tracker

Gamma	X-Ray	UV	Visible	IR	Microwave	Radio





Water Purifier (RO) Sterilization

Ultraviolet (UV) Rays

How They Are Made:

Produced by the sun, very hot bodies, and special lamps.

The Danger: Overexposure causes melanin production (tanning) and can lead to **skin cancer**. The Earth's Ozone Layer is critical because it absorbs most harmful UV radiation.

Board Exam Uses:

1. **Sterilization:** Used to destroy **bacteria** on surgical instruments and in water purifiers (RO systems).
2. **LASIK:** Used in highly precise eye surgeries.

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Spectrum Tracker

Gamma	**X-Ray**	UV	Visible	IR	Microwave	Radio



MEDICAL DIAGNOSTIC X-RAY IMAGING

X-Rays

How They Are Made:

Produced by bombarding a heavy metal target with high-speed electrons. Discovered accidentally by Wilhelm Röntgen.

Penetrating Power:

They easily pass through soft tissue (muscles) but are absorbed by dense materials (bones).

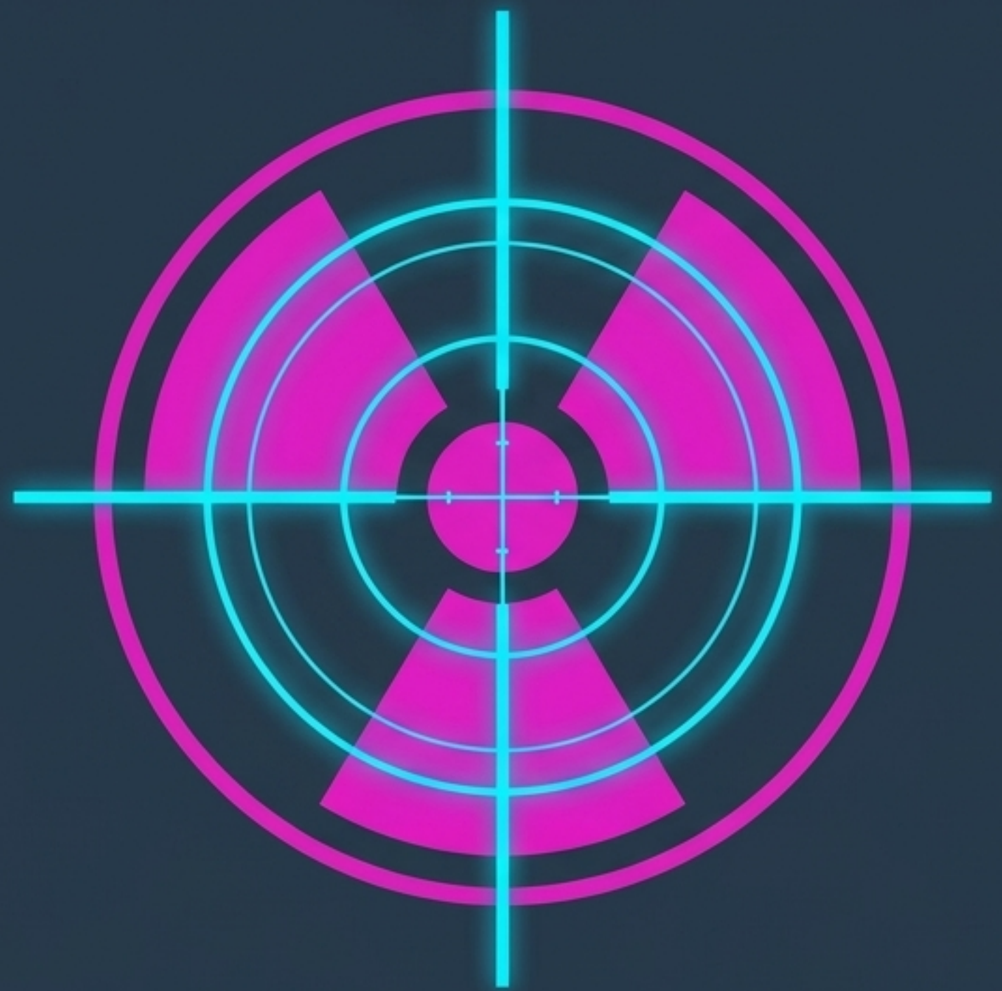
Board Exam Uses:

1. **Medical Diagnostics**: Detecting bone fractures and dental issues.
2. **Industrial**: Detecting cracks, flaws, and bubbles inside solid metal structures.

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Spectrum Tracker

Gamma Rays	X-Ray	UV	Visible	IR	Microwave	Radio



Gamma Rays

Wave Stats: **Shortest Wavelength** | **Highest Frequency** | **Maximum Energy**

How They Are Made:

Emitted spontaneously by radioactive nuclei during nuclear reactions.

Penetrating Power:

Unstoppable by most materials; can penetrate thick concrete and human bone easily.

Board Exam Uses:

1. **Cancer Therapy:** Used in radiotherapy to target and destroy cancerous tumor cells.
2. **Nuclear Studies:** Used to study atomic nuclei structure.

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The Ultimate Board-Exam Cheat Sheet

Increasing Energy / Decreasing Wavelength

Wave Type	Wavelength Trend	Frequency Trend	Top 2 Uses
Radio	Longest λ	Lowest *f*	TV broadcasting, cell phones
Microwave	↓ λ	↑ *f*	Radar systems, microwave ovens
Infrared	↓ λ	↑ *f*	Night vision goggles, muscular therapy
Visible	↓ λ	↑ *f*	Human vision, optical fibers
Ultraviolet	↓ λ	↑ *f*	Sterilizing surgical tools, water purifiers
X-Rays	↓ λ	↑ *f*	Bone fracture imaging, metal crack detection
Gamma	Shortest λ	Highest *f*	Cancer radiotherapy, nuclear structure

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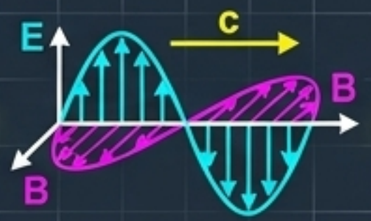


The Universal Blueprint Complete


Spectrum

Synthesis Statement: Maxwell's realization that a changing electric field creates a magnetic field didn't just fix a math equation. It proved that light itself is a self-sustaining electromagnetic wave.

Final Takeaway: From the invisible gap in a charging capacitor to the gamma rays of nuclear fusion, the universe operates on a single, continuous spectrum of oscillating fields.



EM Wave

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