

PHYSICS • CLASS 12

CHAPTER 8

Electromagnetic Waves

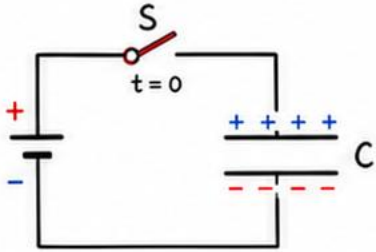
CHAPTER NOTES



ELECTROMAGNETIC WAVES

Electromagnetic waves are coupled time-varying electric and magnetic fields that propagate through space and carry energy.

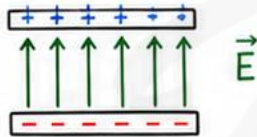
① CHARGING CAPACITOR PARADOX



- When switch S closes, current I flows in the wire.
- Between the plates, E-field builds up but no conduction current flows.
- By Ampère's law (without Maxwell's correction), this seems impossible!

② DISPLACEMENT CURRENT

Maxwell resolved the paradox by introducing displacement current between the plates.



$$I_d = \epsilon_0 \frac{d\Phi_E}{dt} \quad \text{where} \quad \Phi_E = \int \vec{E} \cdot d\vec{A}$$

Now the total current is continuous and Ampère's law is preserved.

③ AMPÈRE-MAXWELL LAW

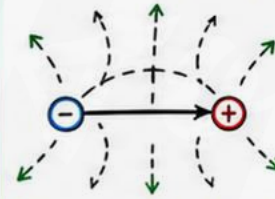
The complete law for magnetostatics and electrodynamics.

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 \left(I_c + \epsilon_0 \frac{d\Phi_E}{dt} \right)$$

Time-varying electric fields (through $d\Phi_E/dt$) produce magnetic fields even without conduction current.

④ ACCELERATED CHARGES RADIATE

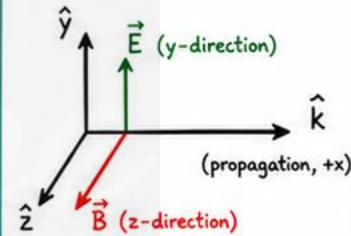
Changing currents require time-varying fields, which cannot remain confined—they propagate away as waves, carrying energy.



Any accelerated charge is a source of EM radiation.

⑤ TRANSVERSE PLANE-WAVE GEOMETRY

In free space, EM waves are transverse: $\vec{E} \perp \vec{B} \perp \vec{k}$ and in phase.

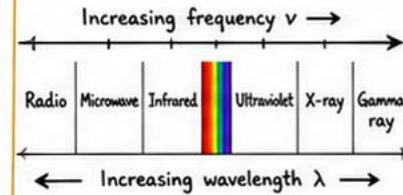


Direction of propagation:

$$\vec{k} \parallel \vec{E} \times \vec{B}$$

⑥ ELECTROMAGNETIC SPECTRUM

All EM waves travel in vacuum with speed c but differ in frequency ν (or wavelength λ).



- Low ν , long λ → Radio
- High ν , short λ → Gamma ray

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \quad \text{and} \quad \nu \lambda = c$$

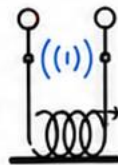
LIGHT IS AN ELECTROMAGNETIC WAVE.

Maxwell prediction

(1864) From his equations, Maxwell predicted EM waves and found their speed equals c .

Hertz verification (1887-1888)

Heinrich Hertz generated and detected radio waves in the laboratory, confirming Maxwell's prediction.



Bose millimetre waves

Jagadish Chandra Bose produced and studied millimetre waves, exploring their reflection, refraction and polarization.

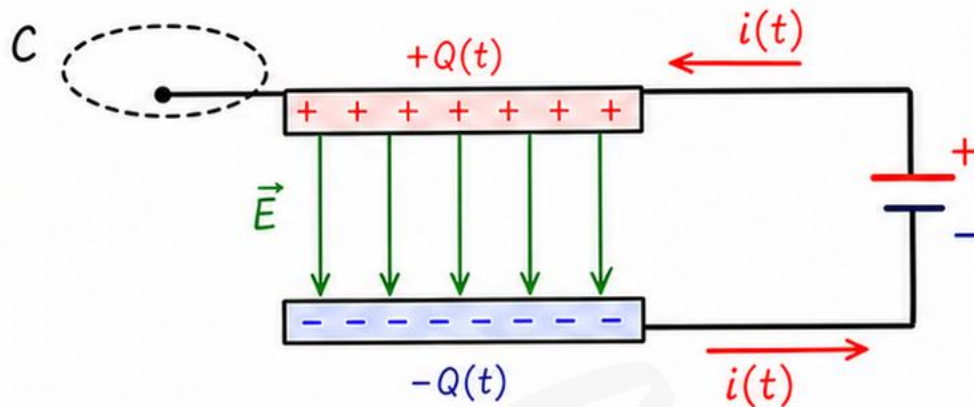


Marconi long-distance communication

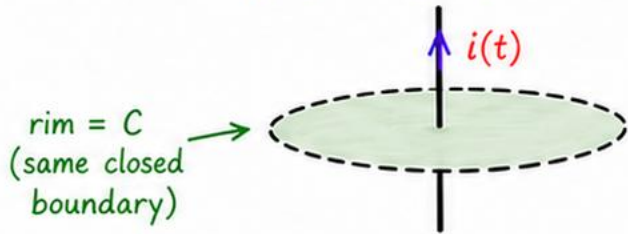
Guglielmo Marconi developed practical wireless telegraphy, enabling long-distance communication across land and sea.



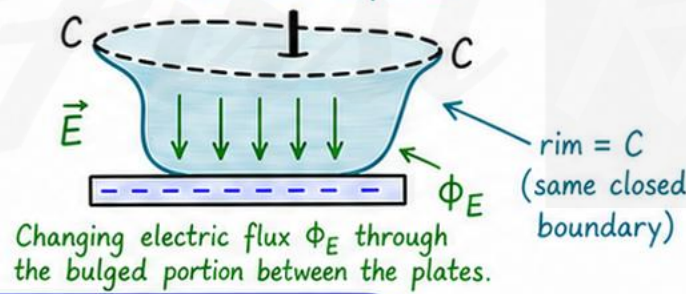
AMPÈRE LAW & THE CAPACITOR PARADOX



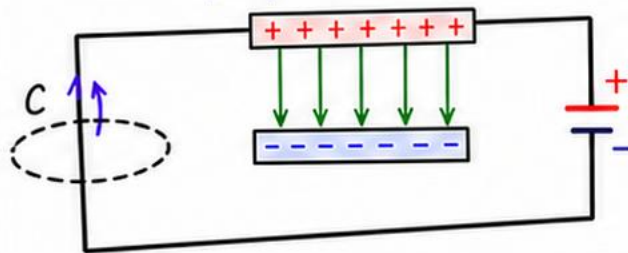
S_1 : flat surface (cuts the wire)



S_2 : pot-shaped surface (between the plates)



3-D inset (perspective view)



Right-hand rule:
Thumb along $i(t)$
(upward). Fingers
curl in the direction
of $\vec{B}$ (CCW as
viewed from above).



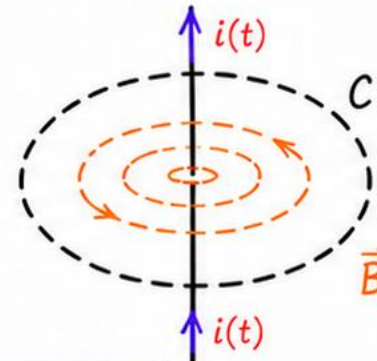
We have a charging parallel-plate capacitor in a circuit carrying time-dependent conventional current $i(t)$. Choose the circular Ampèrian loop C (counterclockwise as viewed from above). It has two different spanning surfaces with the SAME closed rim C .

① Old Ampère law: $\oint_C \vec{B} \cdot d\vec{l} = \mu_0 i_{\text{enclosed}}$

② Using S_1 (the flat disk that cuts the wire):
 $i_{\text{enclosed}} = i(t) \Rightarrow \oint_C \vec{B} \cdot d\vec{l} = \mu_0 i(t)$

③ Using S_2 (the pot-shaped surface between plates):
Conduction current enclosed = 0
 $\Rightarrow \oint_C \vec{B} \cdot d\vec{l} = 0$ (apparently)

④ The SAME LOOP cannot have two magnetic fields!
Therefore, the old Ampère law is incomplete for time-varying fields.



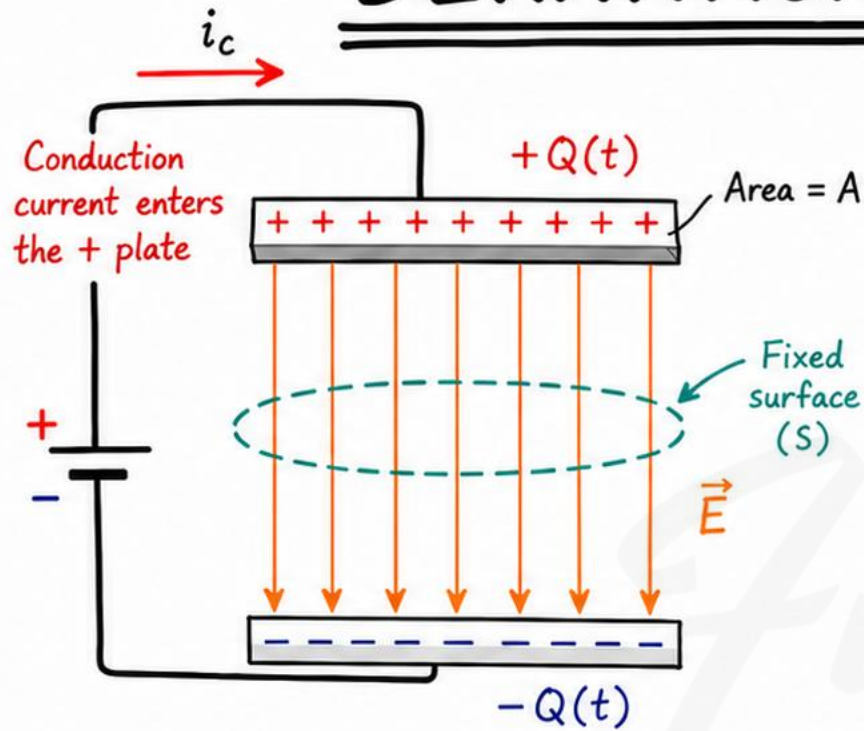
The magnetic field $\vec{B}$
circles the current
axis by the right-
hand rule.

Resolution:

Changing electric
flux ϕ_E
passes through S_2 .

The line integral depends on the boundary C , not on which spanning surface we choose.

DERIVATION — DISPLACEMENT CURRENT



- Upper plate carries $+Q(t)$
- Lower plate carries $-Q(t)$
- Uniform electric field $\vec{E}$ from + to -
- No conduction current crosses the dielectric (ideal capacitor)
- Fringing at edges neglected

Units quick check:

$$[\epsilon_0] = C/V \cdot m \quad \left[\frac{d\Phi_E}{dt} \right] = (V \cdot m)/s$$

$$\text{Therefore } [\epsilon_0 d\Phi_E/dt] = C/s = A.$$

- ① Surface charge density

$$\sigma = \frac{Q}{A}$$

- ② Electric field between plates

$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

- ③ Electric flux through surface (S)

$$\Phi_E = \int_S \vec{E} \cdot d\vec{A} = EA = \frac{Q}{\epsilon_0}$$

- ④ Time rate of change of flux

$$\frac{d\Phi_E}{dt} = \frac{1}{\epsilon_0} \frac{dQ}{dt}$$

- ⑤ Define displacement current

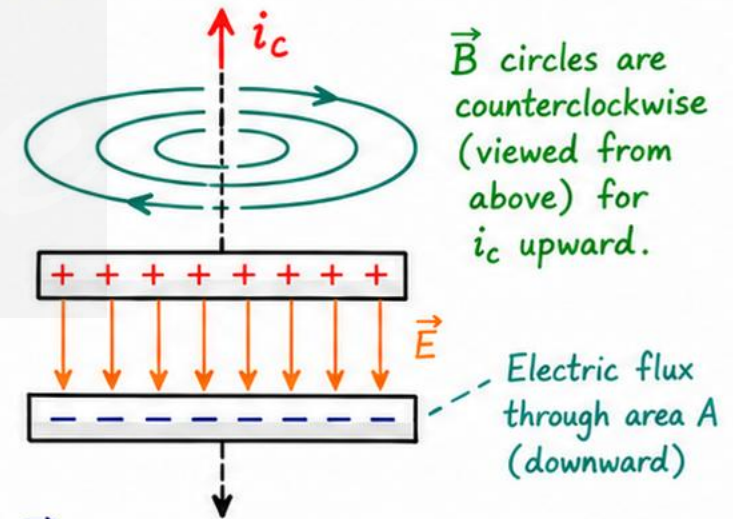
$$i_d = \epsilon_0 \frac{d\Phi_E}{dt}$$

- ⑥ Since conduction current $i_c = \frac{dQ}{dt}$, we obtain

$$i_d = i_c \quad \text{for an ideal charging capacitor}$$

Displacement current is not free charge crossing the dielectric. It is the changing-electric-flux term that produces the required magnetic field.

Right-hand rule (cross-section)



$\vec{B}$ direction is consistent with i_c by the right-hand rule.

Assumptions:

- Ideal parallel plates
- Uniform electric field between plates
- Fringing effects negligible

AMPÈRE-MAXWELL LAW & CURRENT CONTINUITY

Ampère-Maxwell law (integral form):

$$\oint_C \vec{B} \cdot d\vec{l} = \mu_0(i_c + i_d) = \mu_0 i_c + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}.$$

Displacement current is defined as:

$$i_d = \epsilon_0 \frac{d\Phi_E}{dt}.$$

CONDUCTION CURRENT	DISPLACEMENT CURRENT
actual transport of charge carriers.	changing electric flux; not literal charge transport through the gap.

A. WIRE BEFORE PLATE:

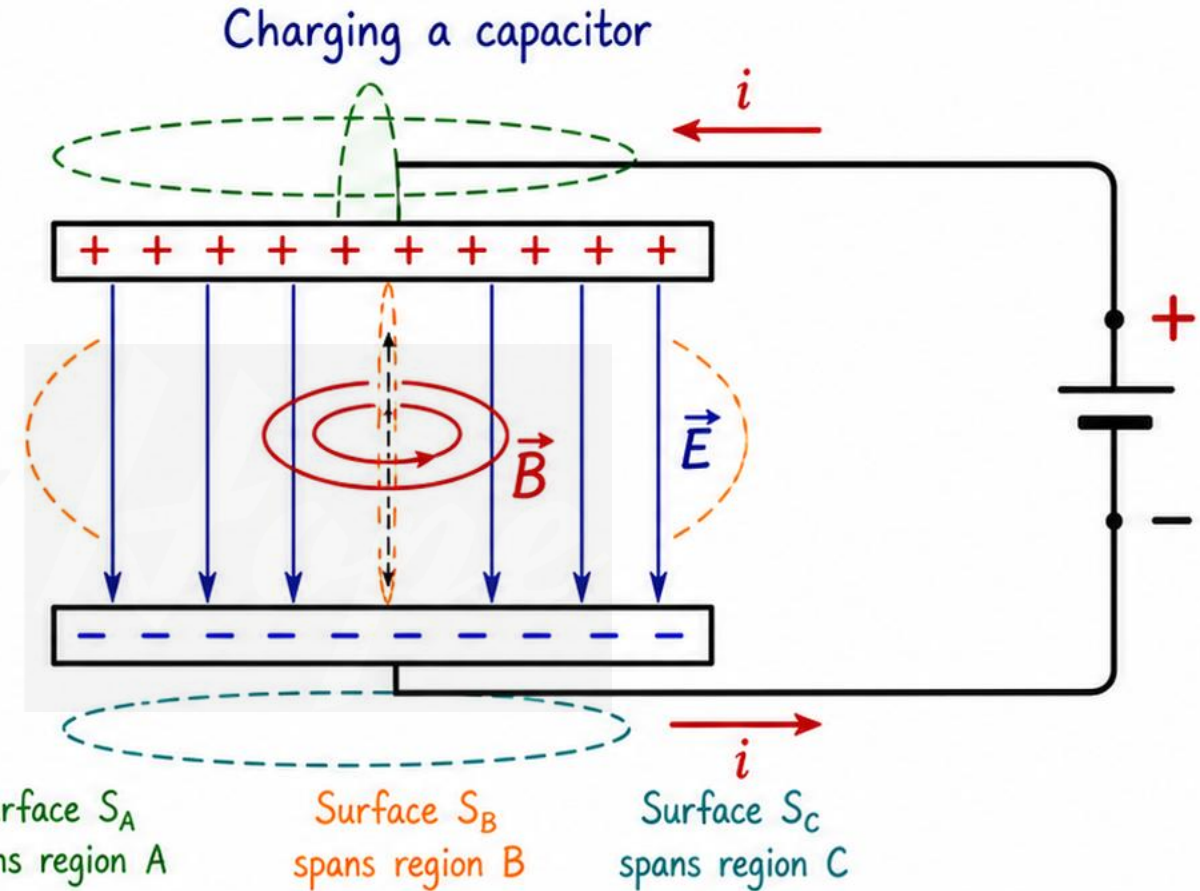
$i_c = i$ and $i_d \approx 0$
in the ideal-wire model.

B. DIELECTRIC GAP:

$i_c = 0$ and $i_d = i$.

C. WIRE AFTER PLATE:

$i_c = i$ and $i_d \approx 0$
in the ideal-wire model.



same total current $i_c + i_d$ through every surface,
so the magnetic field is single-valued.

Both enter the magnetic-field source term; current continuity is preserved.

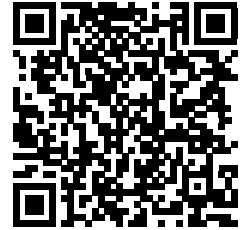


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