

a changing E makes a B , a changing B makes an E , and the pair carries itself forward

Changing E

$$\frac{d\phi_E}{dt}$$

an electric field that varies with time

→ closes the loop

Displacement current

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

Maxwell's term: it makes a B , just as a conduction current does

→ closes the loop

Self-sustaining wave

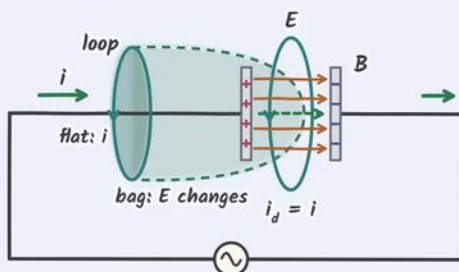
$$E \leftrightarrow B$$

each one's change regenerates the other

without displacement current, Ampere's law gives a B round the wire but none round the gap of a charging capacitor:
Maxwell's term removes the contradiction

Displacement current, said precisely

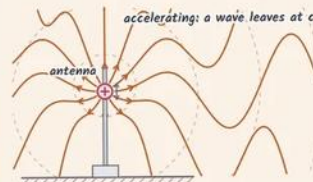
- Ampere's law, one loop: the current i pierces its flat surface
- stretch that surface into a bag between the plates: no charge crosses it
- yet the electric flux through the gap changes as the plates charge
- Maxwell: a changing E is a current too, the displacement current $i_d = \epsilon_0 \frac{d\phi_E}{dt}$
- Ampere-Maxwell law: $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 i_c + \mu_0 \epsilon_0 \frac{d\phi_E}{dt}$
- constant, AC or rising: $i_d = i$ at every instant, the same B
- not a flow of charge, yet it makes B ; steady (dc) state: no i_d



one loop, two surfaces: the current pierces the flat one; through the bag only E changes, and $i_d = i$ gives the same B

Sources: an accelerating charge

- charge at rest: only a steady E , no wave
- steady speed (a steady current): a steady B added, still no wave
- an accelerated charge radiates: oscillating E makes oscillating B , which makes E again
- the wave has the frequency of the charge's oscillation; its energy comes from the source
- Hertz made and detected them (1887); J.C. Bose, waves of a few mm (1895)



a charge oscillating on an antenna: kinks in its field lines travel out at c , an electromagnetic wave



a charge at rest: straight, still field lines, no wave

an accelerating charge is the only source:
a wire carrying a steady current radiates nothing at all