INDUCTION DAY 4: INDUCED ELECTRIC FIELDS

WARMUP Who Pushes the Charges?

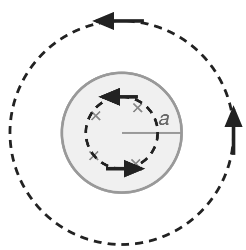
In yesterday's moving bar, $qv \times B$ pushed the charges. But a STATIONARY loop around a ramping solenoid also drives current — nothing moves! What must exist at the loop to push those charges?

FARADAY'S LAW, DEEPEST FORM

$$\oint E \cdot dl = -d\Phi_B/dt$$

Changing B creates a CURLY electric field — closed field lines, no charges needed. Inside a ramping solenoid (radius a): symmetry gives $E \cdot 2\pi r = (dB/dt)\pi r^2$, so **$E = (r/2)dB/dt$** inside; **$E = (a^2/2r)dB/dt$** outside (nonzero even where B = 0!).

No potential map: the round-trip integral is nonzero, so this E has no V. Induced EMFs are energy sources, not potential differences.



shaded disk: the solenoid's cross-section — B points into the page (×) and is GROWING

dashed: circular paths at r < a and r > a — the arrows show the induced E on each

Top view of the ramping solenoid. The induced E forms closed circles — it exists at r > a even though B there is zero.

WE DO Exercise 1: Inside the Solenoid

A solenoid of radius a = 0.10 m ramps at dB/dt = 2.0 T/s. **(a)** E at r = 0.05 m: (r/2)(dB/dt) = _________. **(b)** The EMF around that r = 0.05 m circle: $E \cdot 2\pi r$ = _________.

WE DO **Exercise 2: Outside the Solenoid**

Same solenoid ($a = 0.10$ m, $dB/dt = 2.0$ T/s). **(a)** A loop at $r = 0.20$ m encloses flux only through the solenoid's cross-section πa^2. $E = (a^2/2r)(dB/dt) =$ _________. **(b)** B at that radius is essentially ZERO — yet E is not. One sentence on how.

YOU DO **Exercise 3: A Charge Rides the Loop**

A +2.0 μC charge is carried once around the $r = 0.05$ m circle from Exercise 1. Find the work done on it by the induced field: $W = q\varepsilon$. (For a Coulomb field this round trip would cost ZERO — say why.)

CALC **Exercise 4: Derive Both Profiles**

Run the census twice: for $r < a$ (enclosed flux $\pi r^2 B$) and $r > a$ (enclosed flux $\pi a^2 B$). Derive $E(r)$ in each region, check they agree at $r = a$, and sketch E vs r — the same rise-then-fall profile as B inside a thick wire.

PAPER PRACTICE

PRACTICE PROBLEMS

P1 Inside

Solenoid $a = 0.2$ m ramping at 1.5 T/s: find E at $r = 0.1$ m.

P2 Outside

The same solenoid: find E at $r = 0.4$ m.

P3 EMF on a Ring

A wire ring of radius 0.1 m sits inside that solenoid, centered. Find the EMF driving it: $\varepsilon = \pi r^2 \cdot dB/dt$.

P4 Two Parents of E

Compare the two electric fields of this course: the Coulomb field of charges and the induced field of changing flux. For each: field-line shape, $\oint E \cdot dl$, and whether a potential V exists. One table, three rows.