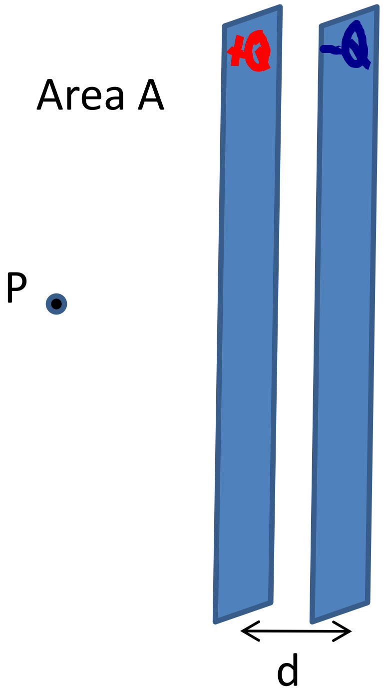
A parallel plate capacitor has two very large plates of area *A* separated by a small distance *d*. It is charged with equal charges of opposite sign. What is the magnitude of the electric field at point P, outside the capacitor?

1) $\dfrac{Q}{\varepsilon_0}$

2) $\dfrac{Q}{A\varepsilon_0}$

3) $\dfrac{Q}{2A\varepsilon_0}$

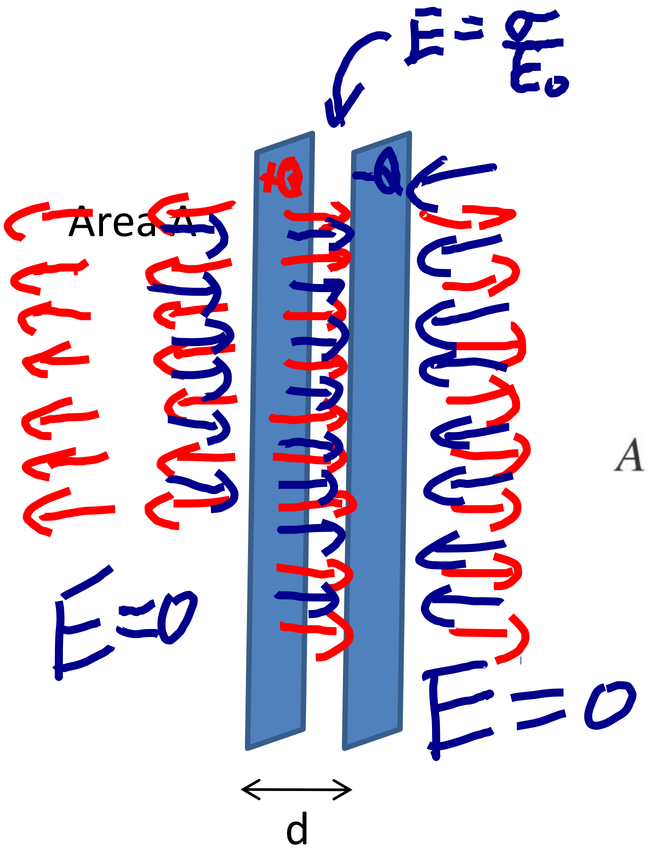
4) Zero.

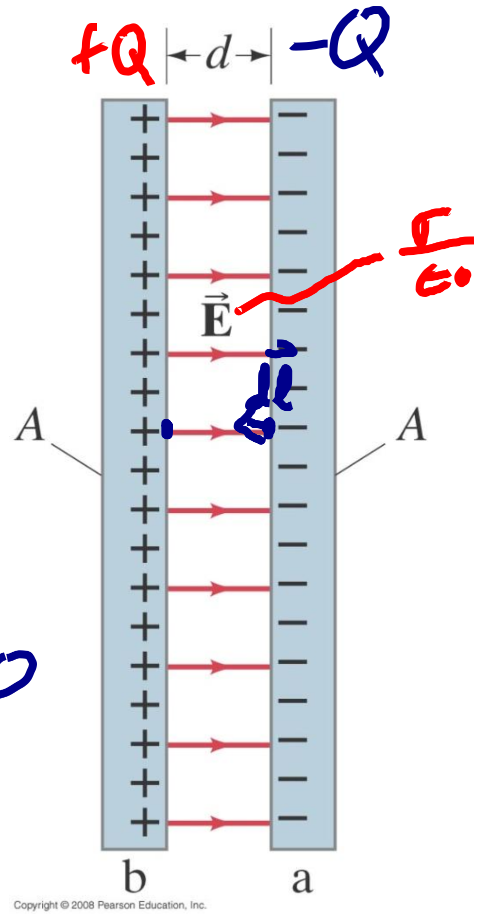


Parallel-plate Capacitor

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

- Electric Field for "infinite" sheet of charge: $E = \frac{\sigma}{2\varepsilon_0}$





$$\Delta V = V_b - V_a = -\int_a^b \vec{E}\cdot d\vec{l}$$

$$\vec{E}\cdot d\vec{l} = -E\,dl$$

$$\Delta V = -\int_a^b -E\,dl$$

$$= \int_a^b E\,dl$$

$$= E\int_a^b dl$$

$$\boxed{\Delta V = Ed}$$

James Clerk Maxwell (1831 – 1879)

- Put electromagnetism on a solid theoretical footing.
- Unified electromagnetism and optics by showing that light "is an electromagnetic disturbance propagated through the field." (1864)
- Devised a method to take the first color photographs.

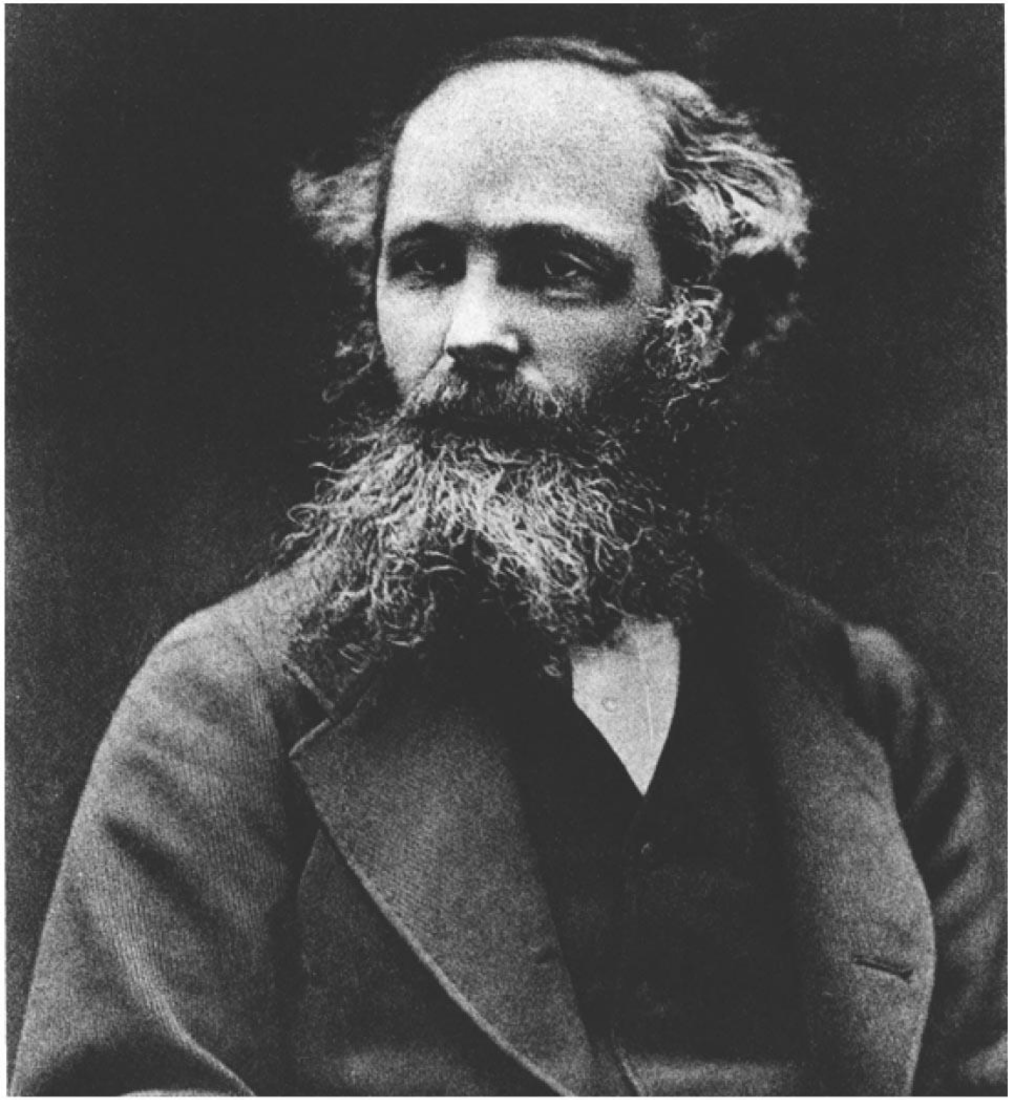
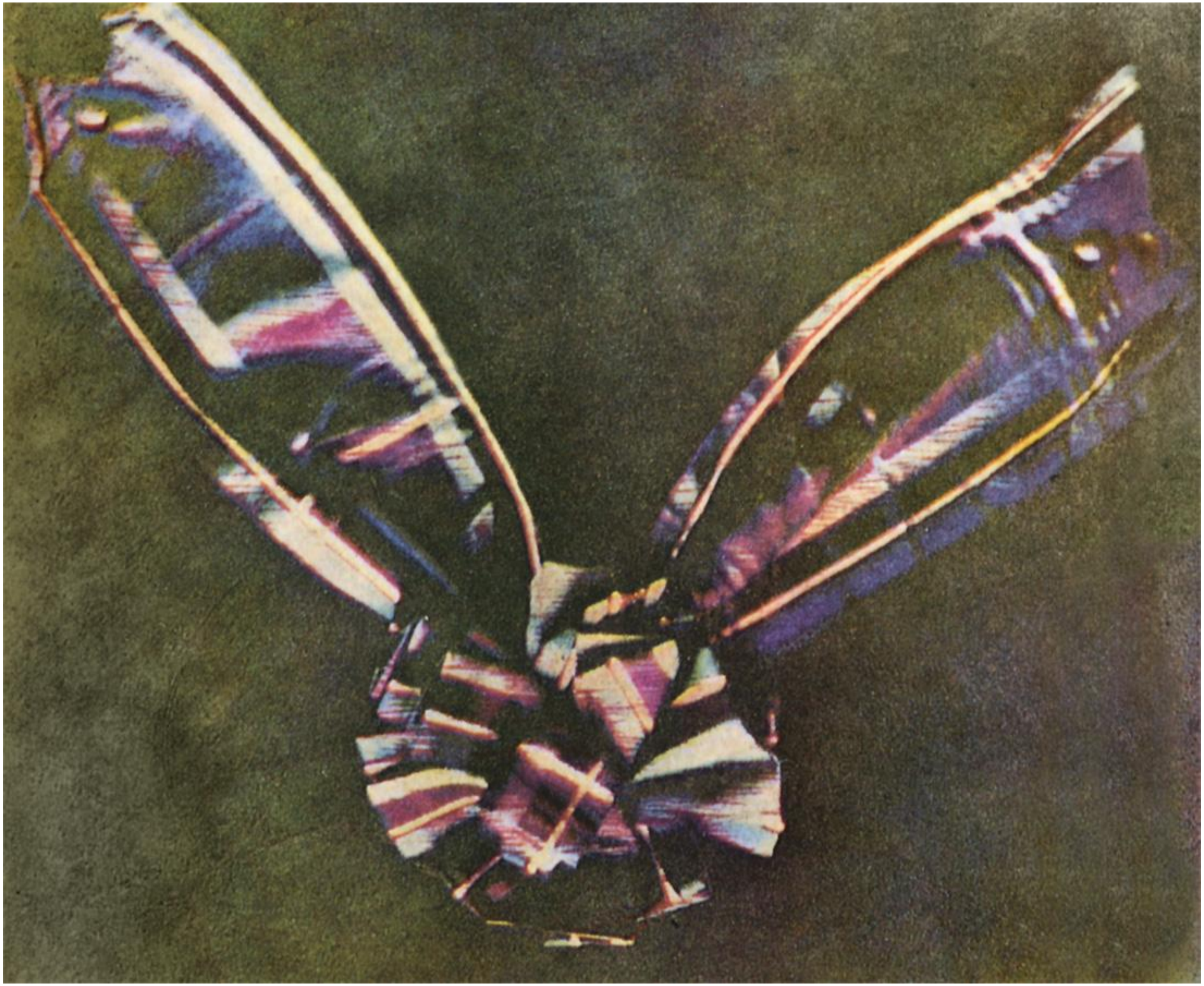


Figure 31.1



http://en.wikipedia.org/wiki/Color_photography

Maxwell's Equations – The Fundamental Laws of Electromagnetism

- Gauss' Law
  - The total electric flux through a closed surface is proportional to the charge enclosed:

$$\oint_S \vec{\mathbf{E}} \bullet \hat{\mathbf{n}} dA = \frac{Q_{encl}}{\varepsilon_0}$$

- Gauss' Law for Magnetism
  - The total magnetic flux through a closed surface is zero.
  - There are no magnetic charges.

$$\oint_S \vec{\mathbf{B}} \bullet \hat{\mathbf{n}} dA = 0$$

Maxwell's Equations – The Fundamental Laws of Electromagnetism

- Faraday's Law
  - When the magnetic flux through some loop (C) changes, it induces an emf around the loop proportional to the rate of change of the magnetic flux.

$$\mathcal{E} = -N\frac{d\Phi_B}{dt} = -N\frac{d}{dt}\int \vec{\mathbf{B}} \bullet \hat{\mathbf{n}}\, dA$$

Faraday's Law

- A changing magnetic field induces a *curly* electric field – one for which you cannot define a potential *V*.

$$\mathcal{E} = \oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = -\frac{d}{dt}\int \vec{\mathbf{B}} \cdot \hat{\mathbf{n}}\, dA$$

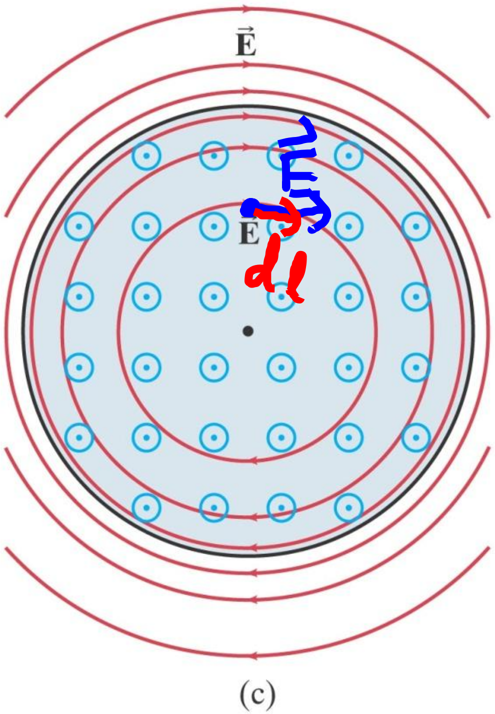
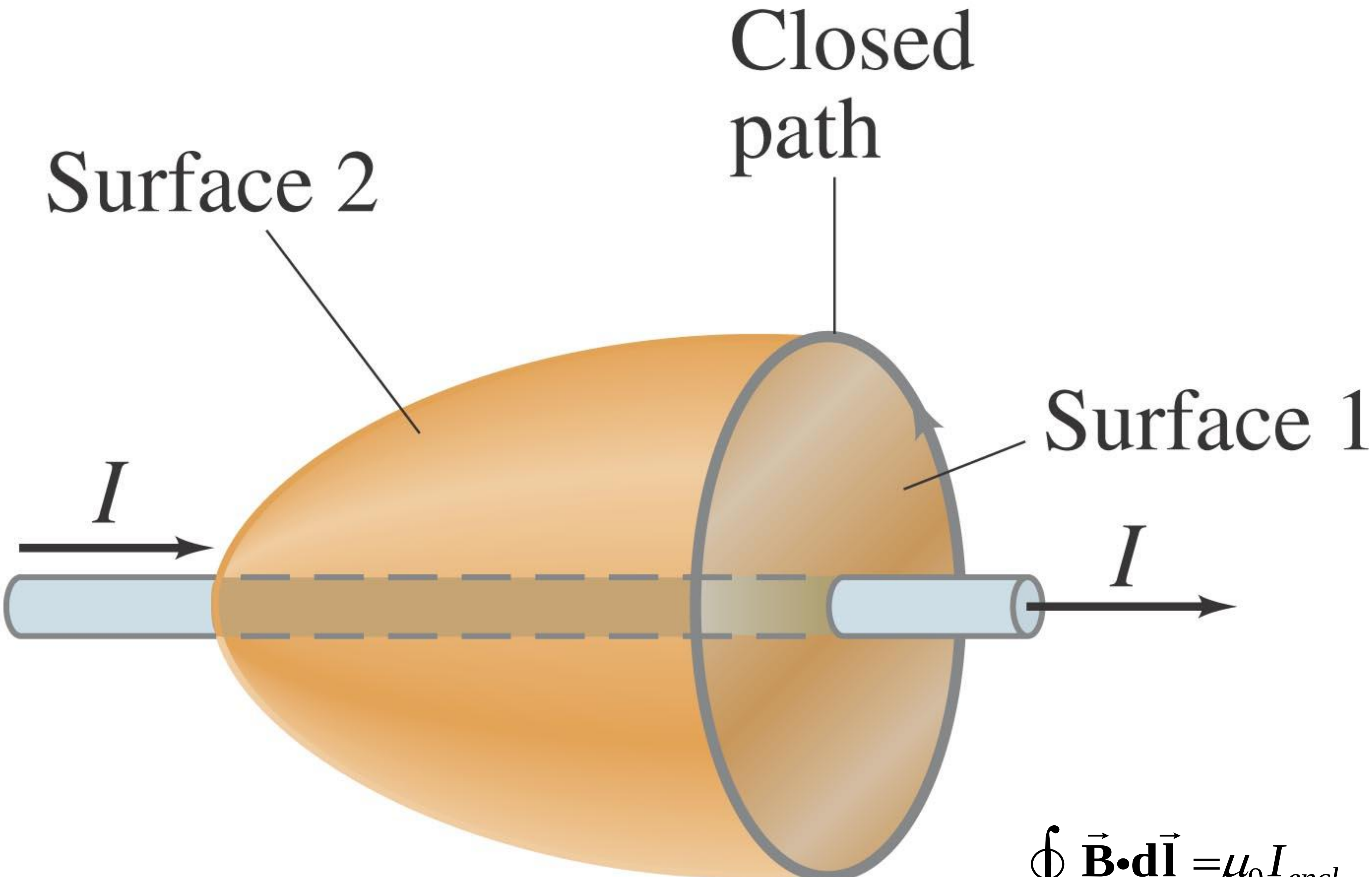


Figure 29.27c

Maxwell's Equations – The Fundamental Laws of Electromagnetism

- Ampere's Law (valid for constant currents)
  - The integral of $\vec{\mathbf{B}} \bullet d\vec{l}$ is proportional to the current piercing a surface bounded by the curve.
  - This Law needs generalization to the case of non-constant currents.

$$\oint_{C} \vec{\mathbf{B}} \bullet \mathbf{d}\vec{\mathbf{l}} = \mu_0 I_{encl}$$



$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 I_{encl}$$

Figure 31.2

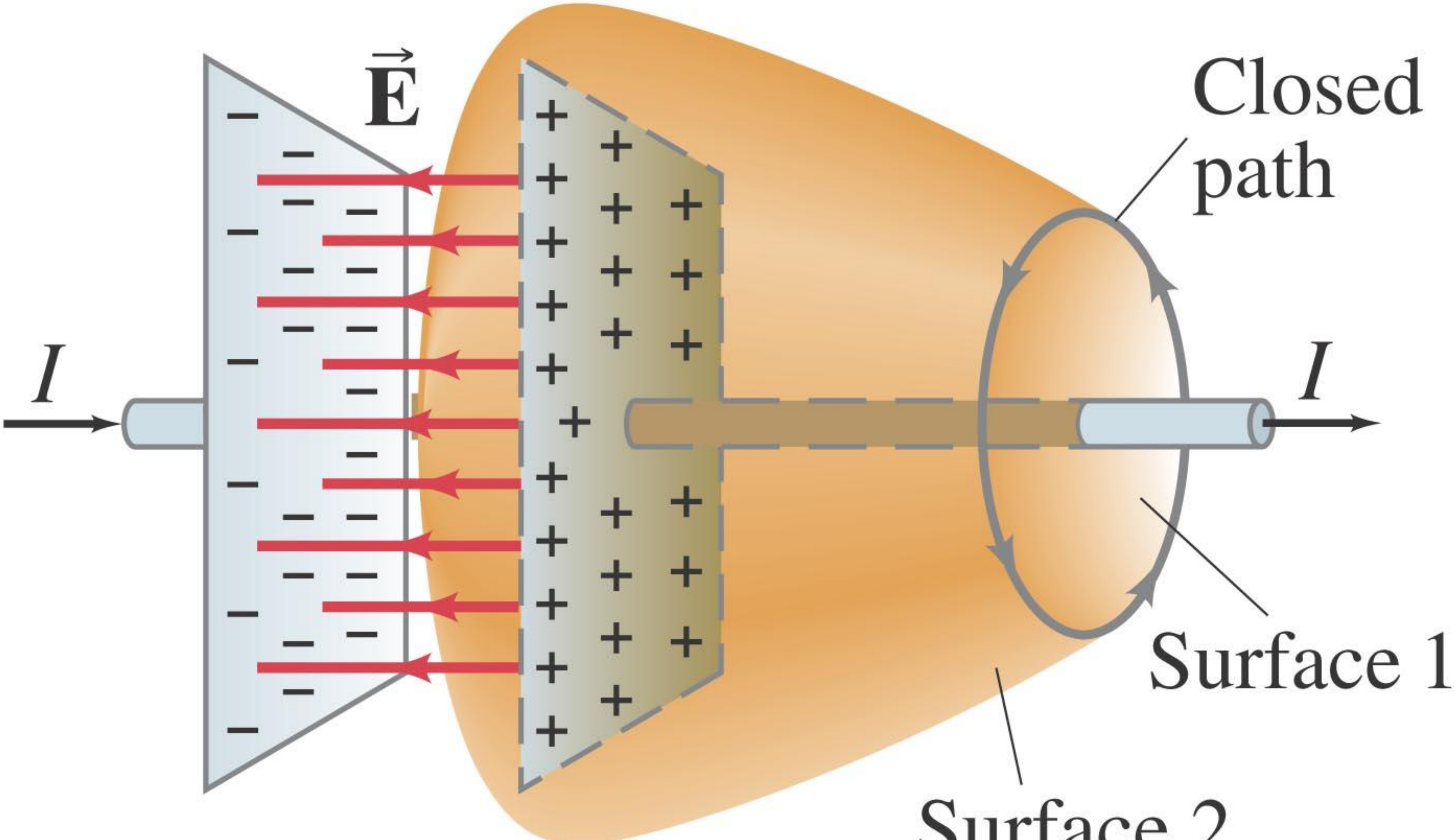


Figure 31.3

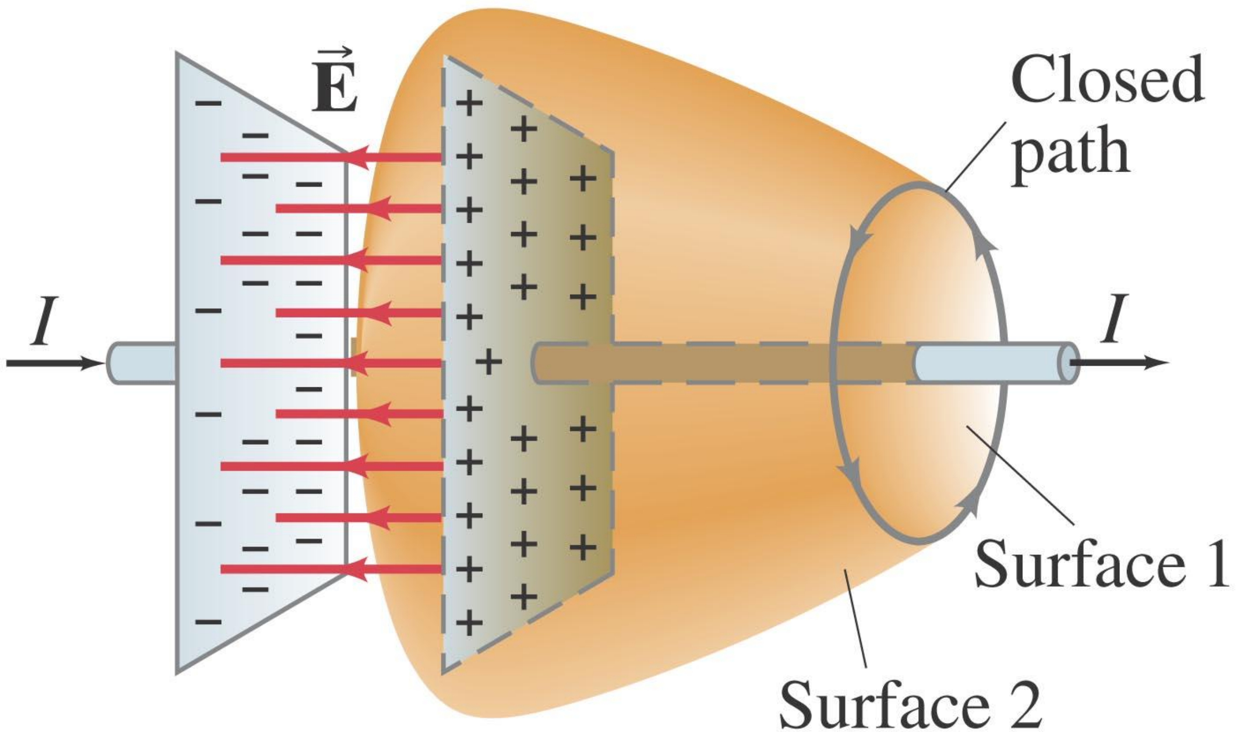
What is the total electric flux through Surface 1?

1) $\frac{Q}{\varepsilon_0}$

2) $\frac{Q}{A\varepsilon_0}$

3) $\mu_0 I$

4) Zero.



What is the total electric flux through Surface 2?

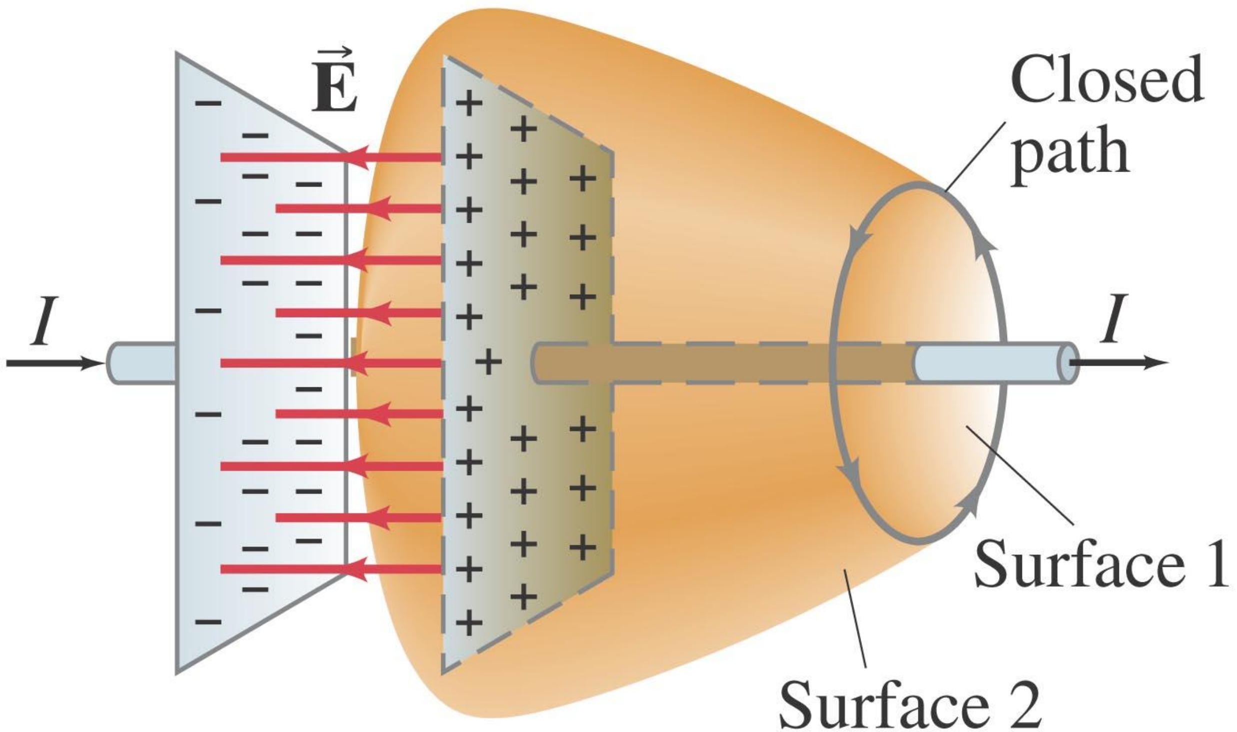
1) $\frac{Q}{\varepsilon_0}$

2) $\frac{Q}{A\varepsilon_0}$

3) $\mu_0 I$

4) Zero.

5) Need more information.



- Gauss' Law
  - The total electric flux through a closed surface is proportional to the charge enclosed:

$$\oint \vec{\mathbf{E}} \bullet \hat{\mathbf{n}}\, dA = \frac{Q_{encl}}{\varepsilon_0}$$

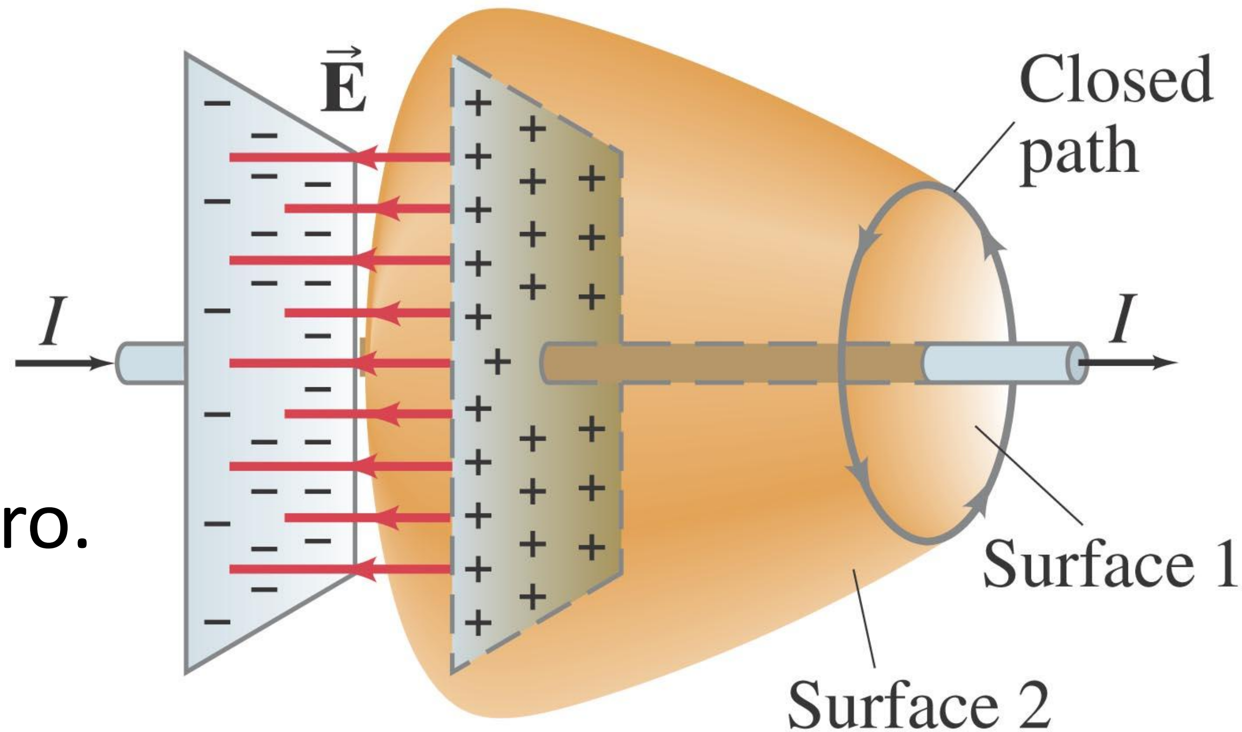
$$\cancelto{0}{\int_{S_1} \vec{E}\cdot\hat{n}\, dA} + \int_{S_2} \vec{E}\cdot\hat{n}\, dA = \frac{Q}{\epsilon_0}$$

$$\Phi_E^{(S2)} = \frac{Q}{\epsilon_0}$$

How is the current through Surface 1 related to the total electric flux through Surface 2?

1) $I_1 = \varepsilon_0 \Phi_E^{(S2)}$

2) $I_1 = \varepsilon_0 \dfrac{d\Phi_E^{(S2)}}{dt}$

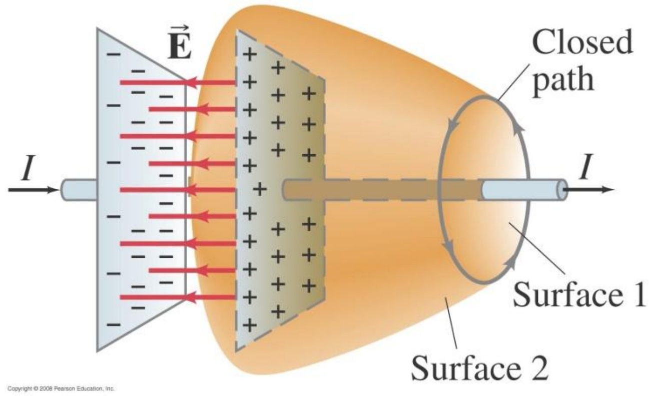


3) Both are zero.

4) They are not related.

5) Need more information.

What do the two surfaces have in common?



- Surface S1:
  - Electric Flux = 0 so $\varepsilon_0 \dfrac{d\Phi_E^{(S1)}}{dt} = 0$
  - Current piercing the surface is I_1.
- Surface S2:
  - Electric Flux is changing: $\varepsilon_0 \dfrac{d\Phi_E^{(S2)}}{dt}$
  - No current pierces surface.
- For both surfaces the sum $I + \varepsilon_0 \dfrac{d\Phi_E}{dt}$ is the same.

displacement current

The Maxwell-Ampere Law

- The integral of $\vec{\mathbf{B}} \bullet d\vec{l}$ around a closed curve is proportional to the current piercing a surface bounded by the curve plus ε_0 times the time rate of change of electric flux through the surface.

$$\oint \vec{\mathbf{B}} \bullet \mathbf{d}\vec{\mathbf{l}} = \mu_0 \left(I_{encl} + \varepsilon_0 \frac{d\Phi_E}{dt} \right)$$

$$\oint \vec{\mathbf{B}} \bullet \mathbf{d}\vec{\mathbf{l}} = \mu_0 \left(I_{encl} + \varepsilon_0 \frac{d}{dt} \int \vec{\mathbf{E}} \bullet \hat{\mathbf{n}} \, dA \right)$$

Faraday’s Law

- The integral of $\vec{\mathbf{E}} \bullet d\vec{l}$ around a closed curve is proportional the time rate of change of magnetic flux through a surface that is bounded by the curve.

$$\oint \vec{\mathbf{E}} \bullet \mathbf{d}\vec{\mathbf{l}} = -\frac{d}{dt}\int \vec{\mathbf{B}} \bullet \hat{\mathbf{n}}\, dA$$

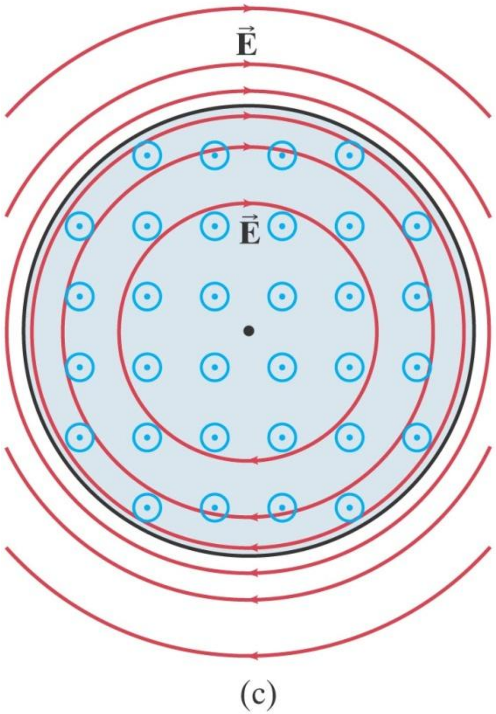


Figure 29.27c