物理学・物理学概論
第11回

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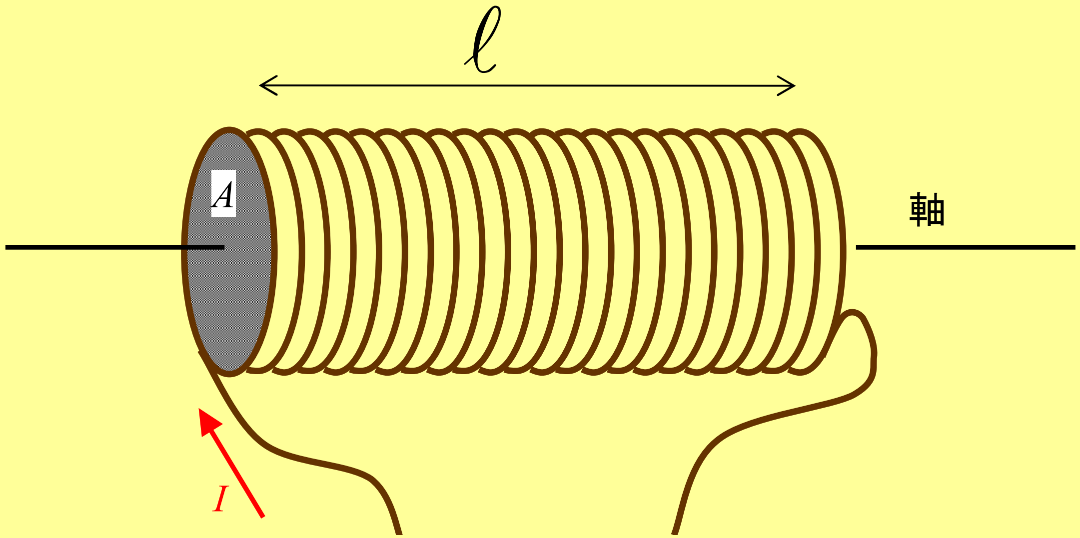
先週のポイント

・アンペアの法則
電流と磁場の関係

・ファラデーの法則
時間的に変化する磁場と
起電力

・インダクタンス（コイル）



$$L = \frac{N\Phi_m}{I} = N\mu(\frac{NA}{\ell})I / I$$

$$L = \frac{N\Phi_m}{I} = \mu\frac{N^2 A}{\ell}$$

$$L = \frac{U}{\frac{dI}{dt}} = \left[\mathrm{V} \cdot \mathrm{s} \middle/ \mathrm{A} \right]$$

H：ヘンリー

$$Q = CV$$

$$I = C\frac{dV}{dt}$$

$$Q = CV$$

$$I = C\frac{dV}{dt}$$

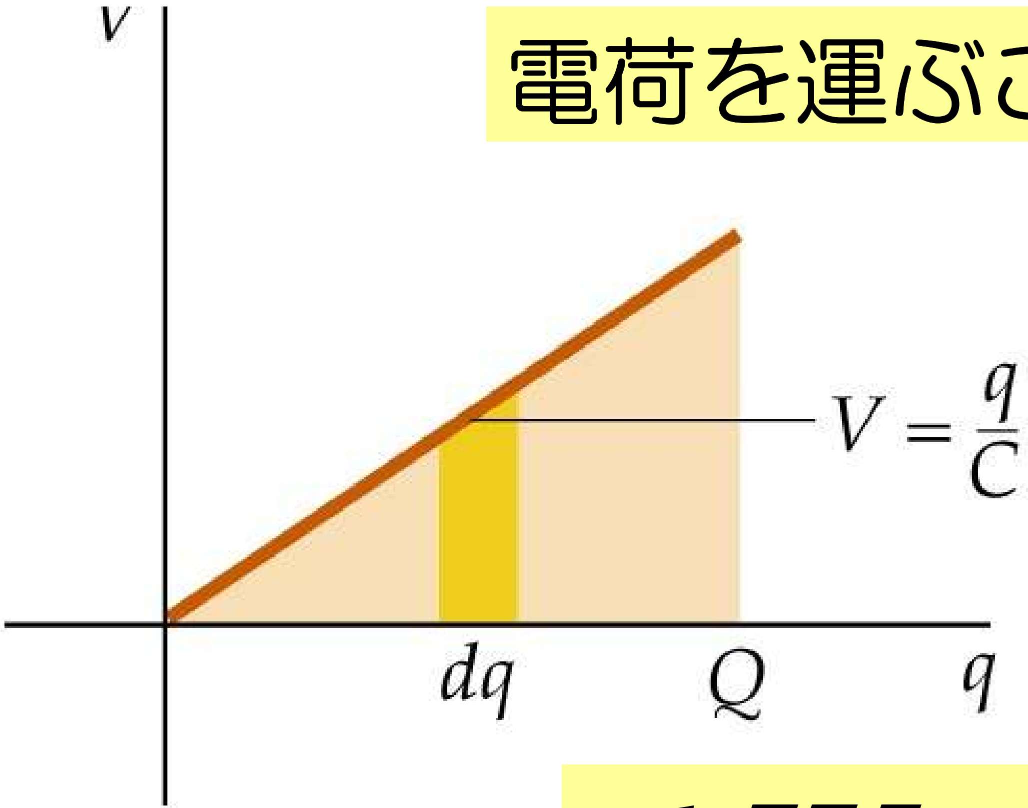
$$C = \frac{I}{\frac{dV}{dt}} = \left[\mathrm{A \cdot s}/\mathrm{V}\right]$$

・磁場（インダクタンス）
の持つエネルギー

・コンデンサ、
インダクタンスをもつ回路
と過渡応答

電荷を運ぶごとにする仕事

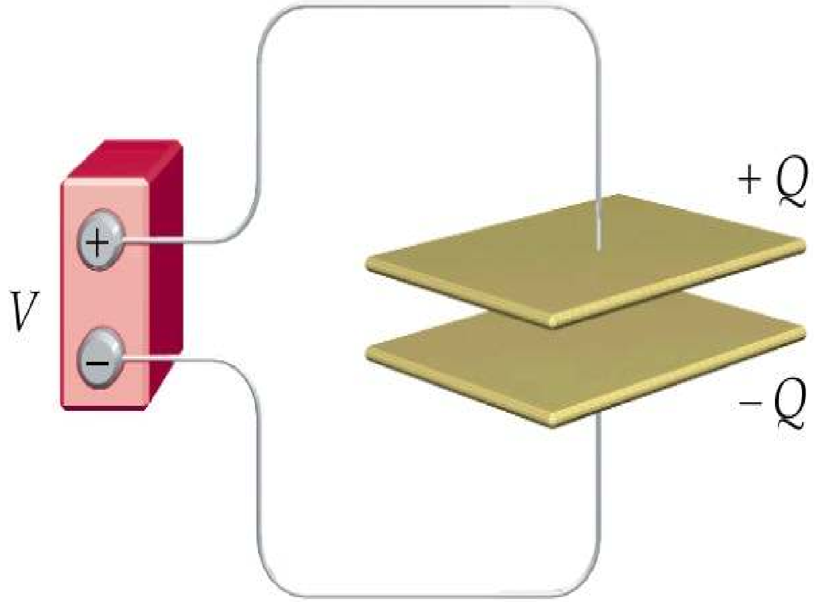
復習1



$$Q = CV$$

$$dW = V \cdot dq$$

$$dW = \frac{q}{C} \cdot dq$$



$$dW = V \cdot dq$$

$$dW = \frac{q}{C} \cdot dq$$

$$\int dW = \int_0^Q \frac{q}{C} \cdot dq$$

$$= \frac{Q^2}{2C} = \frac{QV}{2} = \frac{1}{2} \cdot CV^2$$

$$P = IV,$$

$$W = \int P dt$$

$$I = C\frac{dV}{dt}$$

$$W = \int (C\frac{dV}{dt}) \cdot V dt$$

$$= C\int V \cdot \frac{dV}{dt} \cdot dt = \frac{1}{2}CV^2$$

$$P = IV,$$

$$W = \int P dt$$

$$V = L\frac{dI}{dt}$$

$$W = \int (L\frac{dI}{dt}) \cdot I dt$$

$$= L\int I \cdot \frac{dI}{dt} \cdot dt = \frac{1}{2} L I^2$$

$$Q = CV$$

$$N\Phi_m = LI$$

$$U = -N \frac{d}{dt}(\Phi_m)$$

$$\boxed{I = C \frac{dV}{dt}}$$

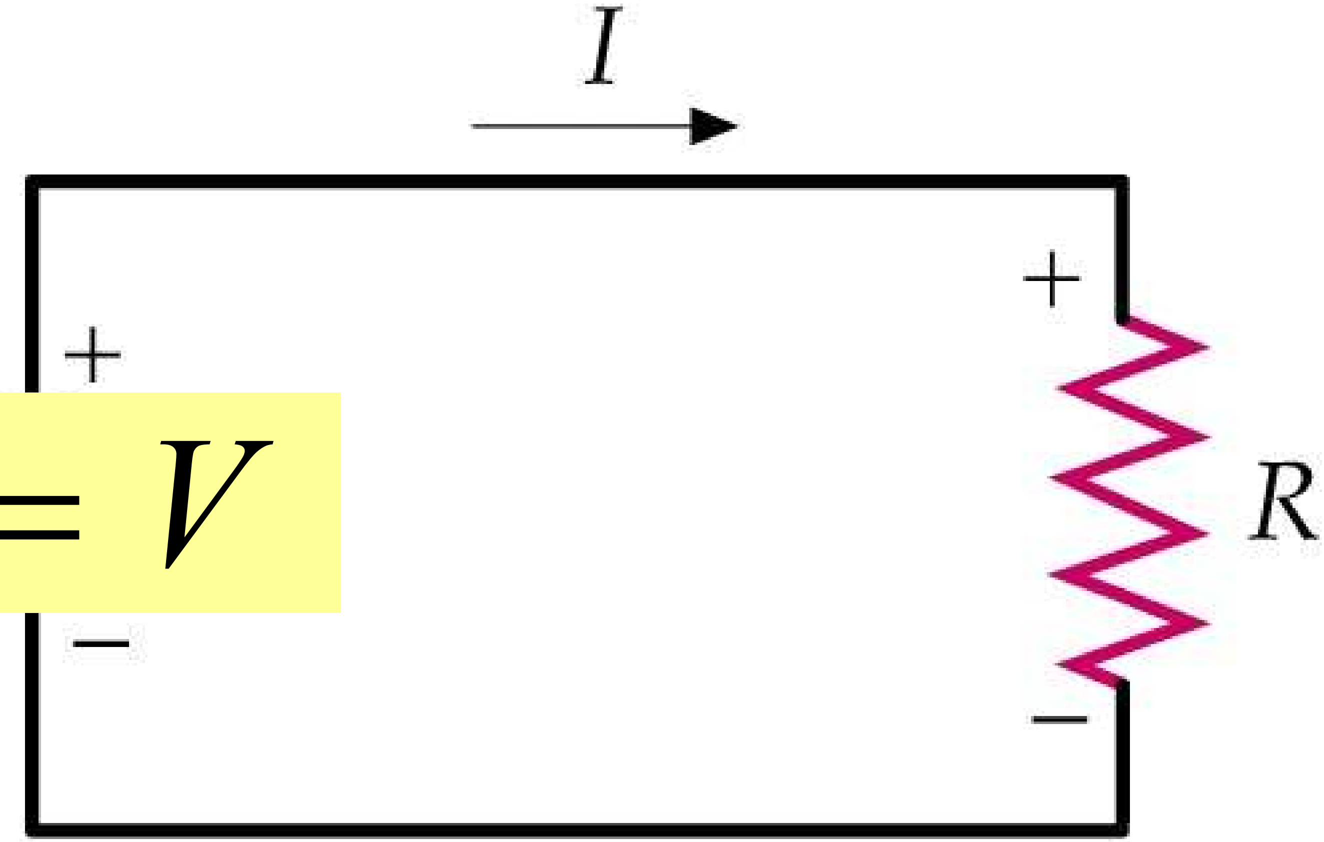
$$\boxed{V = L \frac{dI}{dt}}$$

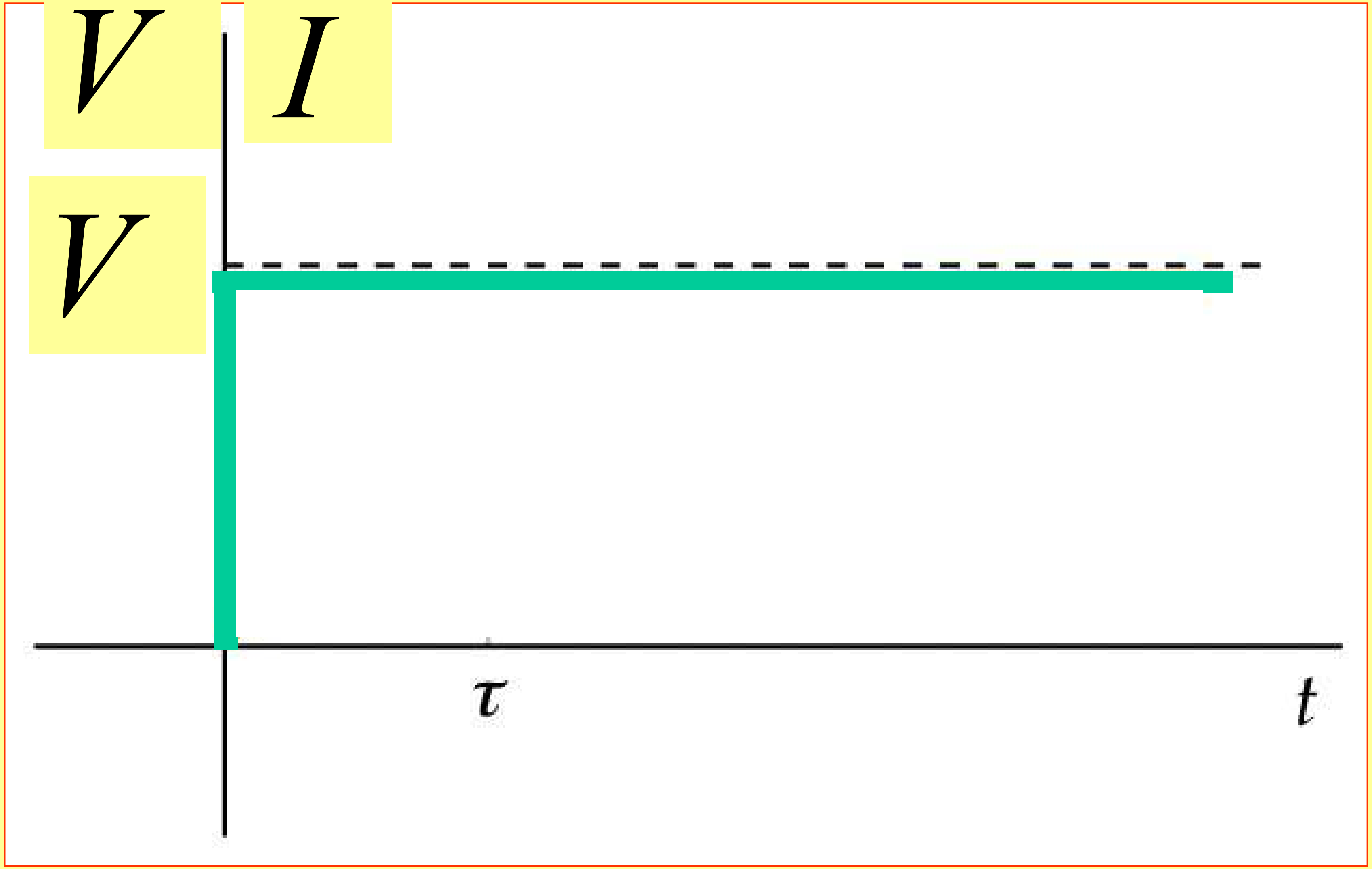
$$Q=CV \qquad N\Phi_m = LI$$

$$I = C\frac{dV}{dt} \qquad V = L\frac{dI}{dt}$$

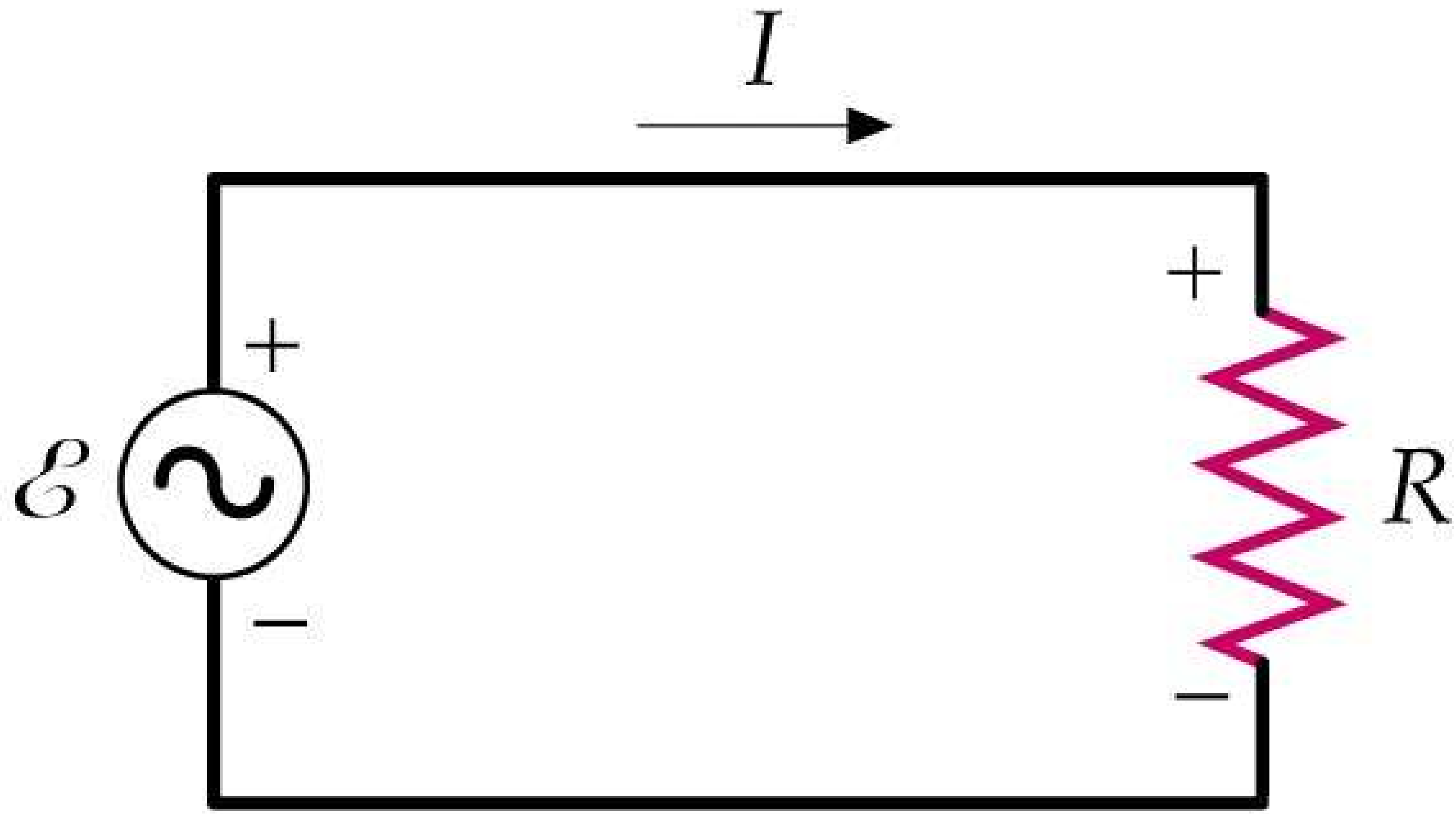
$$W = \frac{1}{2}CV^2 \qquad W = \frac{1}{2}LI^2$$

$$\varepsilon = V$$

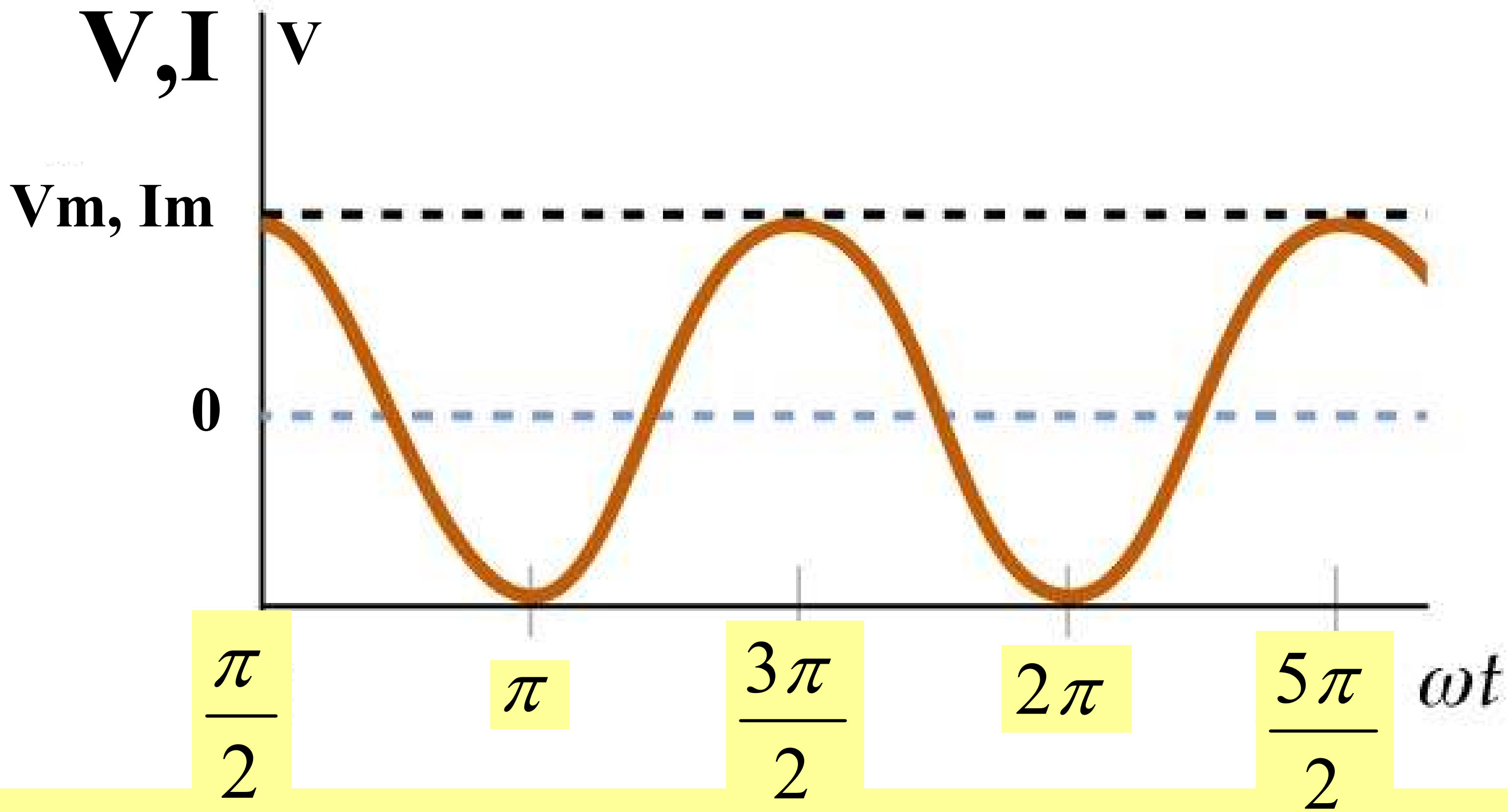




V
I
V
τ
t

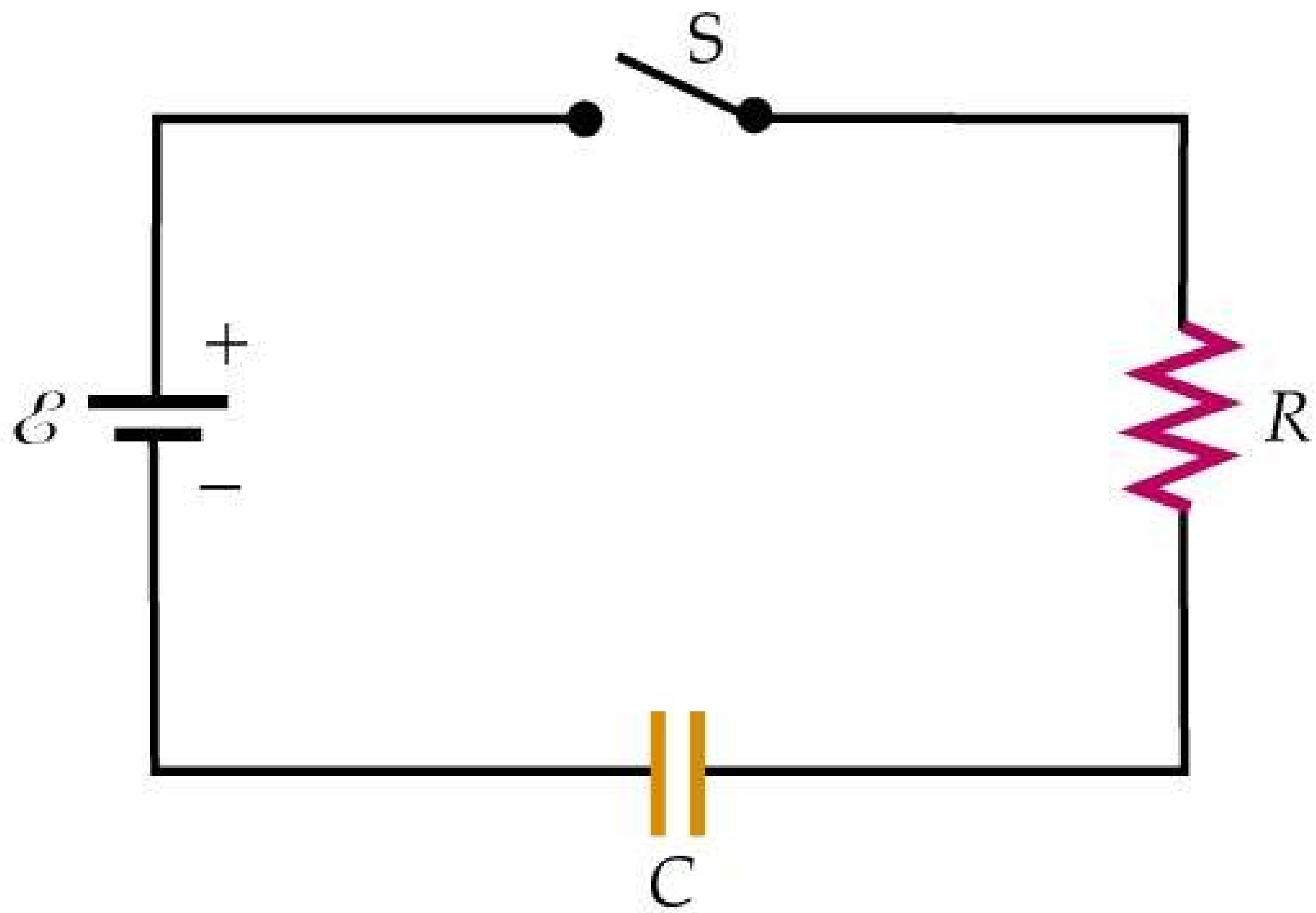


$$\varepsilon = Vm \cdot \sin \omega t$$

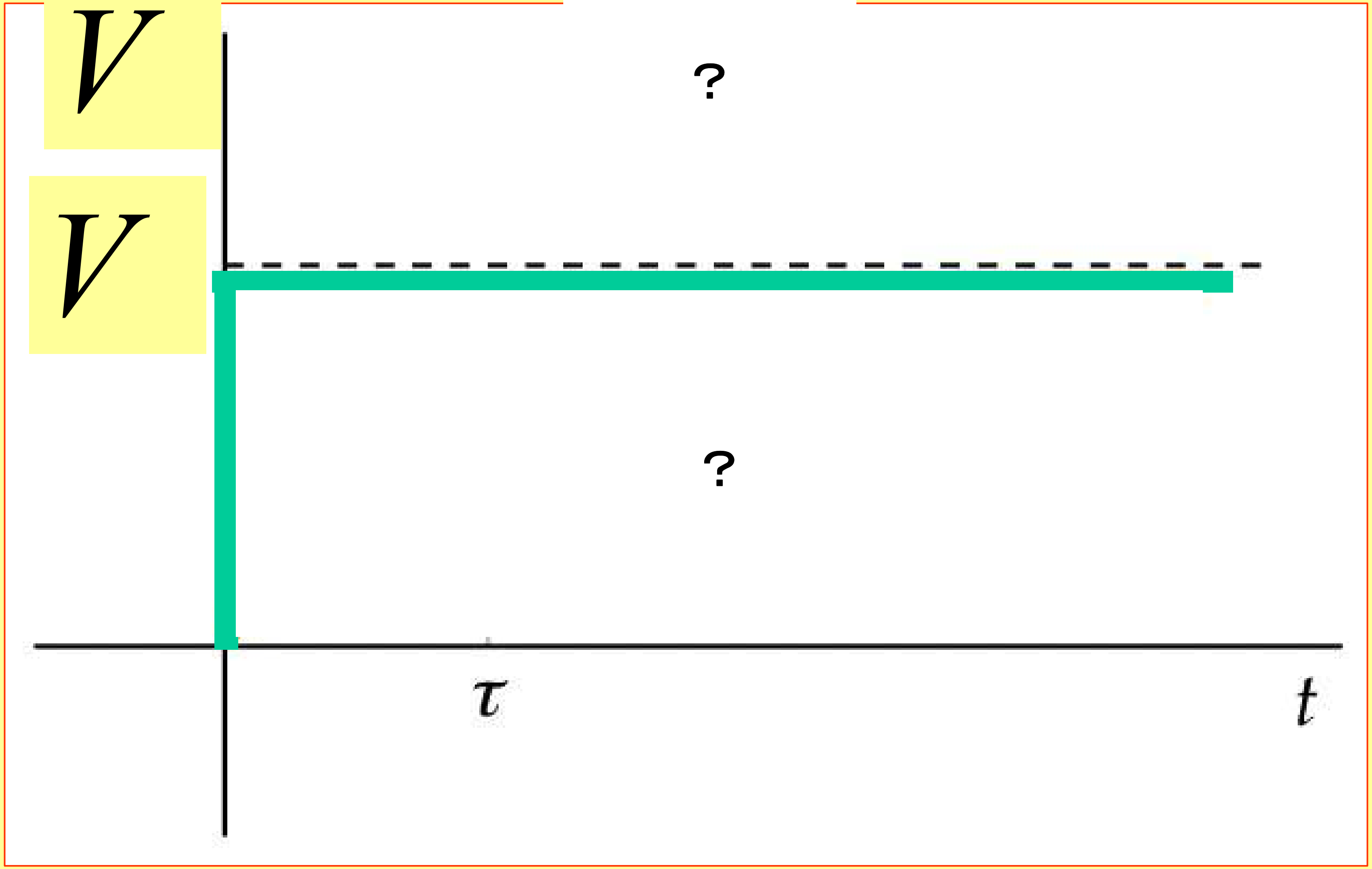


$$V = Vm \cdot \sin \omega t$$

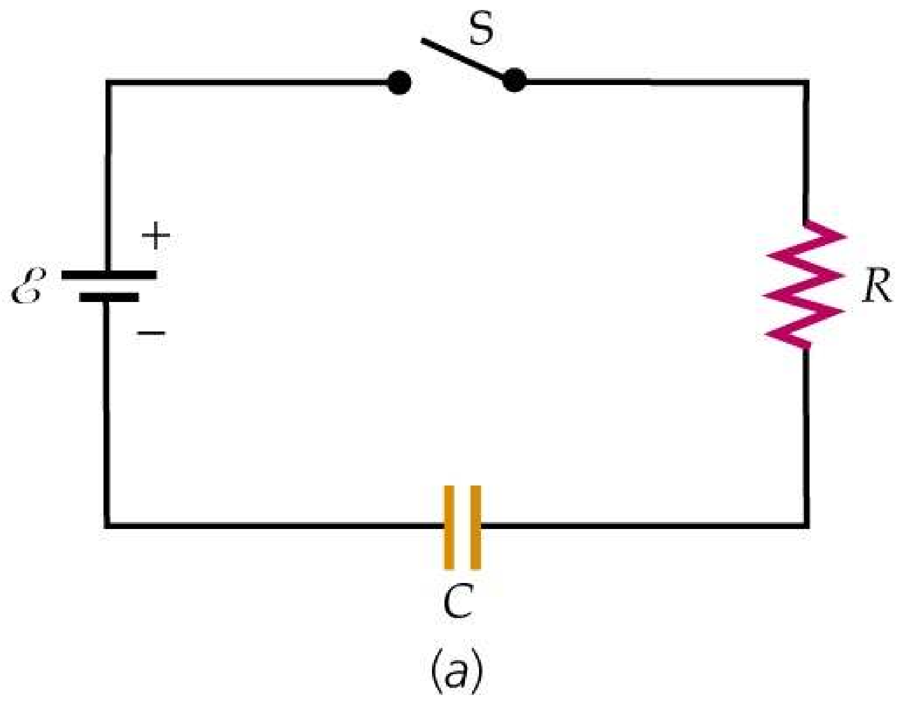
$$I = Im \cdot \sin \omega t$$



(a)



V
V
?
?
τ
t



$$I(t)\cdot R+\frac{Q(t)}{C}=V$$

$$I(t) \cdot R + \frac{Q(t)}{C} = V$$

$$\frac{dQ(t)}{dt} \cdot R + \frac{Q(t)}{C} = V$$

$$\frac{dQ}{dt} \cdot R + \frac{Q}{C} = V$$

$$\frac{dQ}{dt} = \frac{1}{RC}(CV - Q)$$

$$\frac{dQ}{dt} = \frac{(CV - Q)}{RC}$$

$$\frac{dQ}{(CV - Q)} = \frac{dt}{RC}$$

$$\frac{dQ}{(Q - CV)} = -\frac{dt}{RC}$$

$$\frac{dQ}{(Q - CV)} = -\frac{dt}{RC}$$

$$\int \frac{dQ}{(Q - CV)} = -\frac{1}{RC}\int dt$$

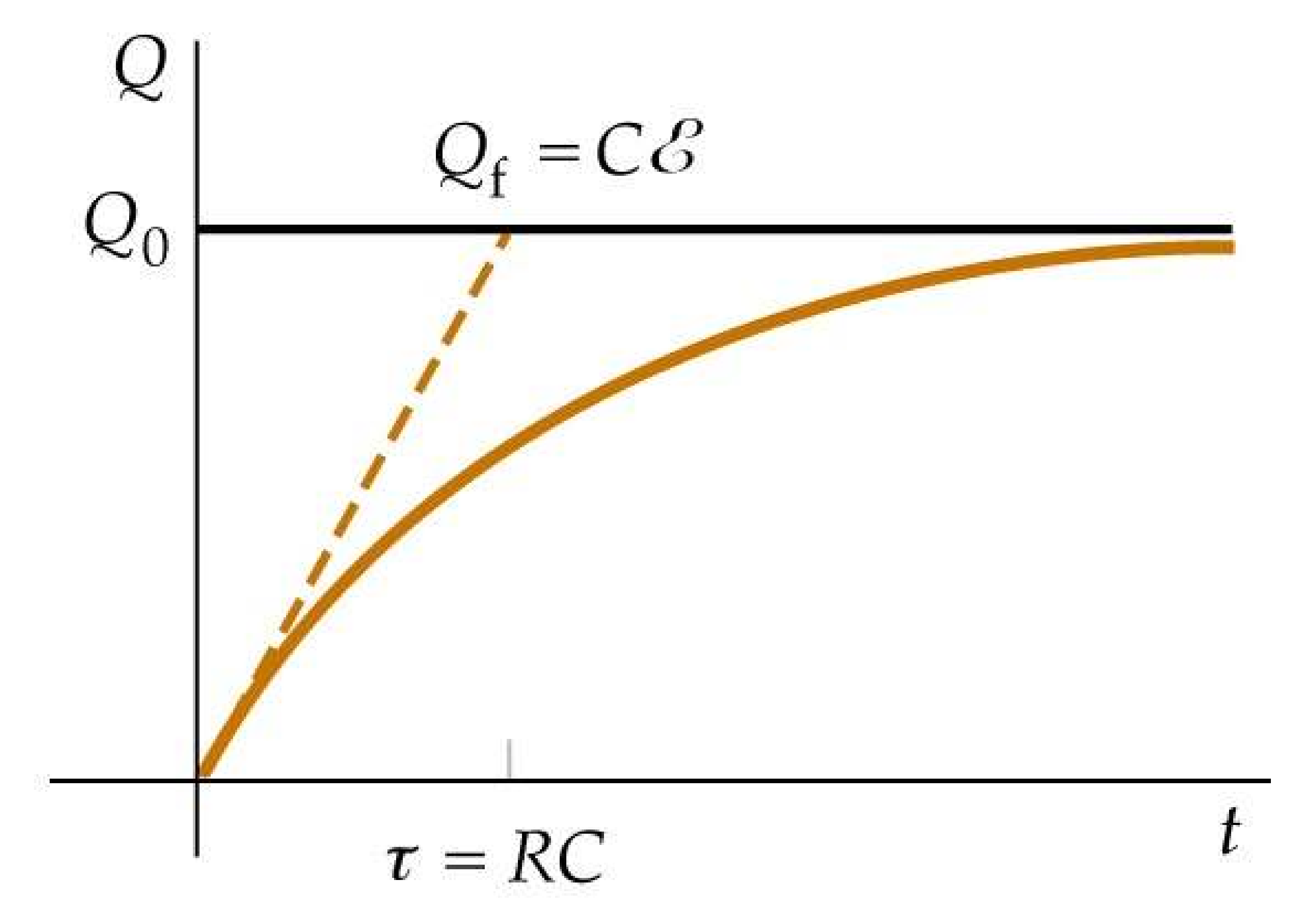
$$\ln(Q - CV) = -\frac{t}{RC}$$

$$\ln(Q - CV) = -\frac{t}{RC}$$

$$Q - CV = A\exp[-\frac{t}{RC}]$$

$$t = 0, Q = 0 \Rightarrow A = CV$$

$$Q = CV\{1 - \exp(-\frac{t}{RC})\}$$



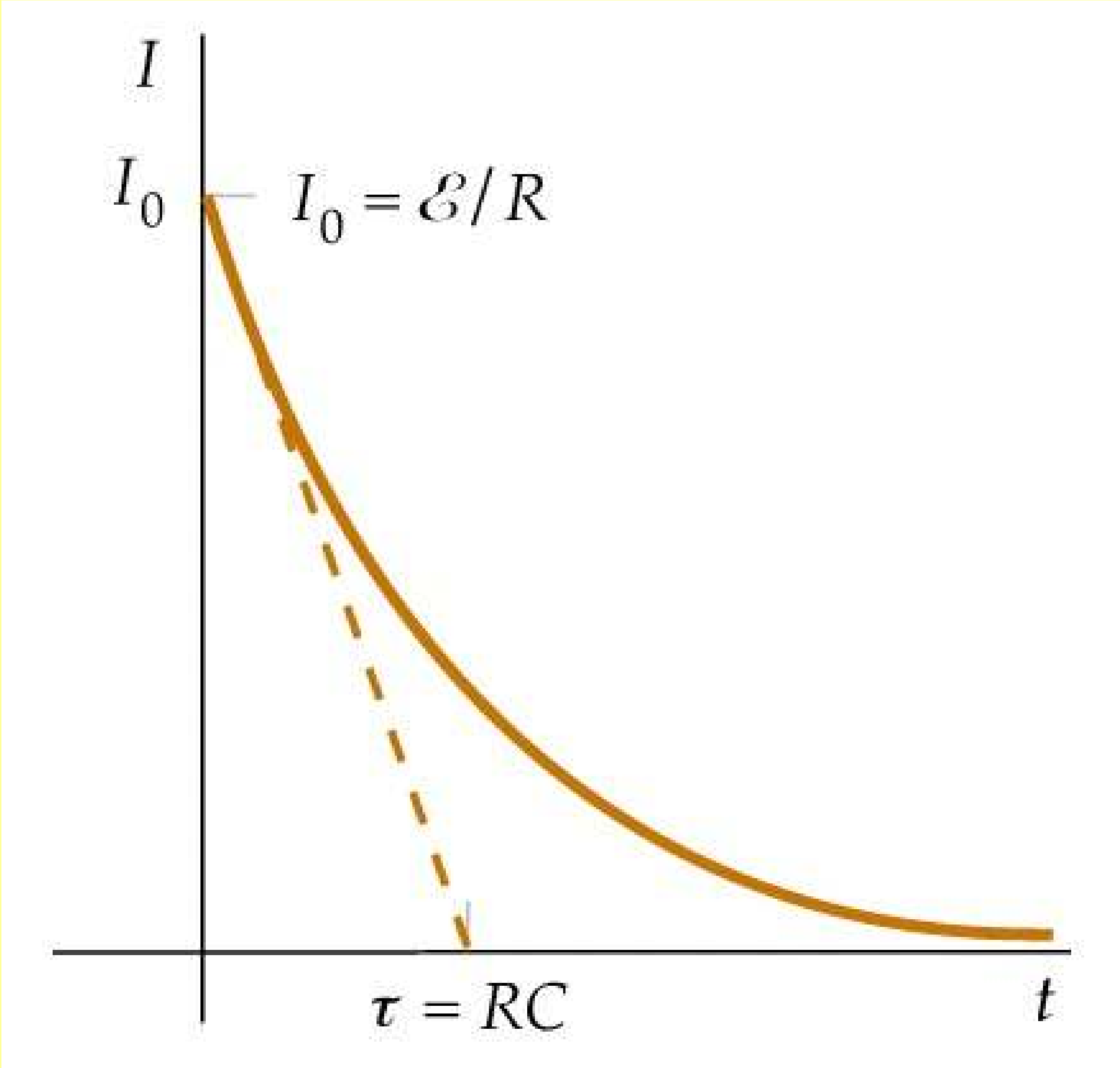
Q
$Q_f = C\mathcal{E}$
Q_0
$\tau = RC$
t

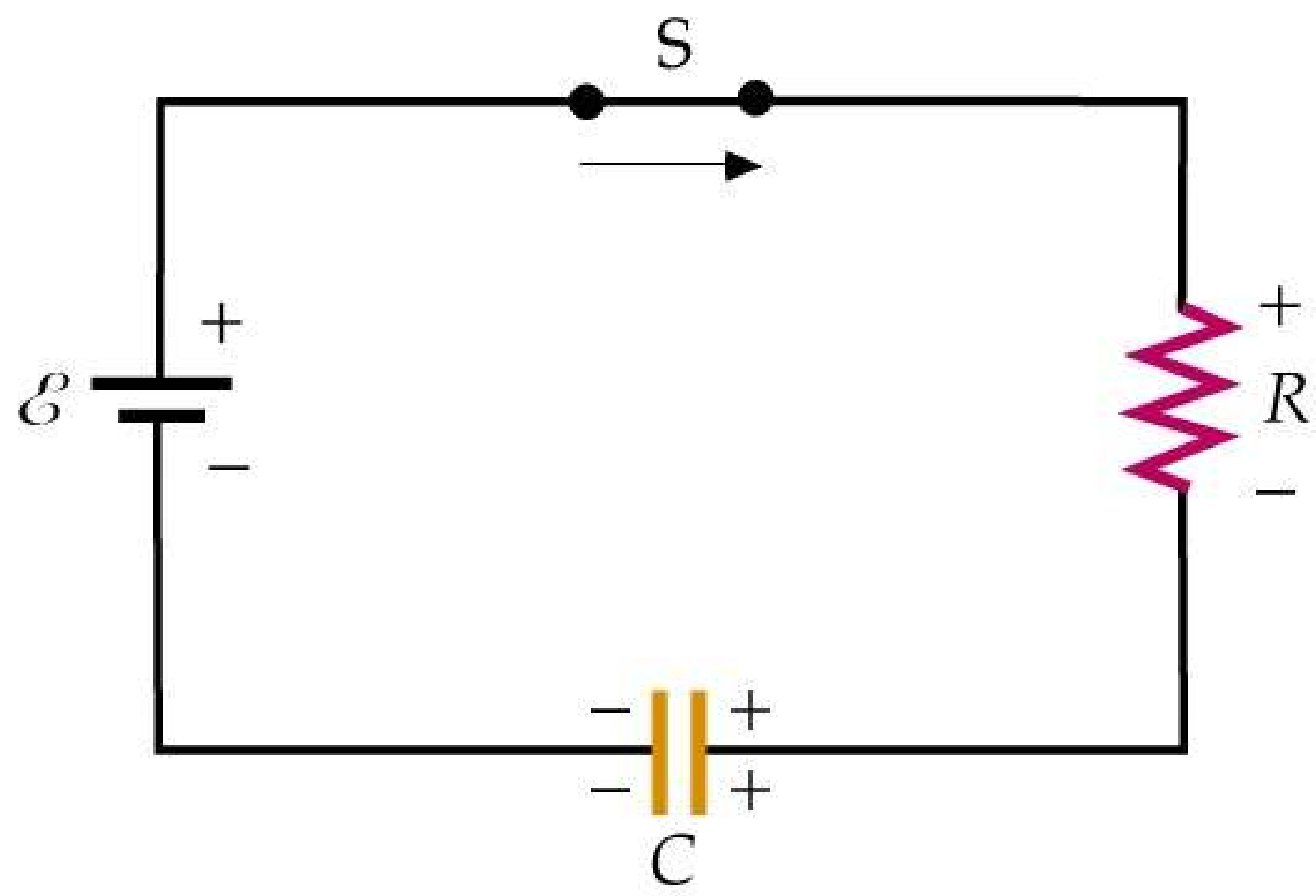
$$\frac{dQ}{dt} = I$$

$$I = \frac{d}{dt}\left[CV\ \{1 - \exp(-\frac{t}{RC})\} \right]$$

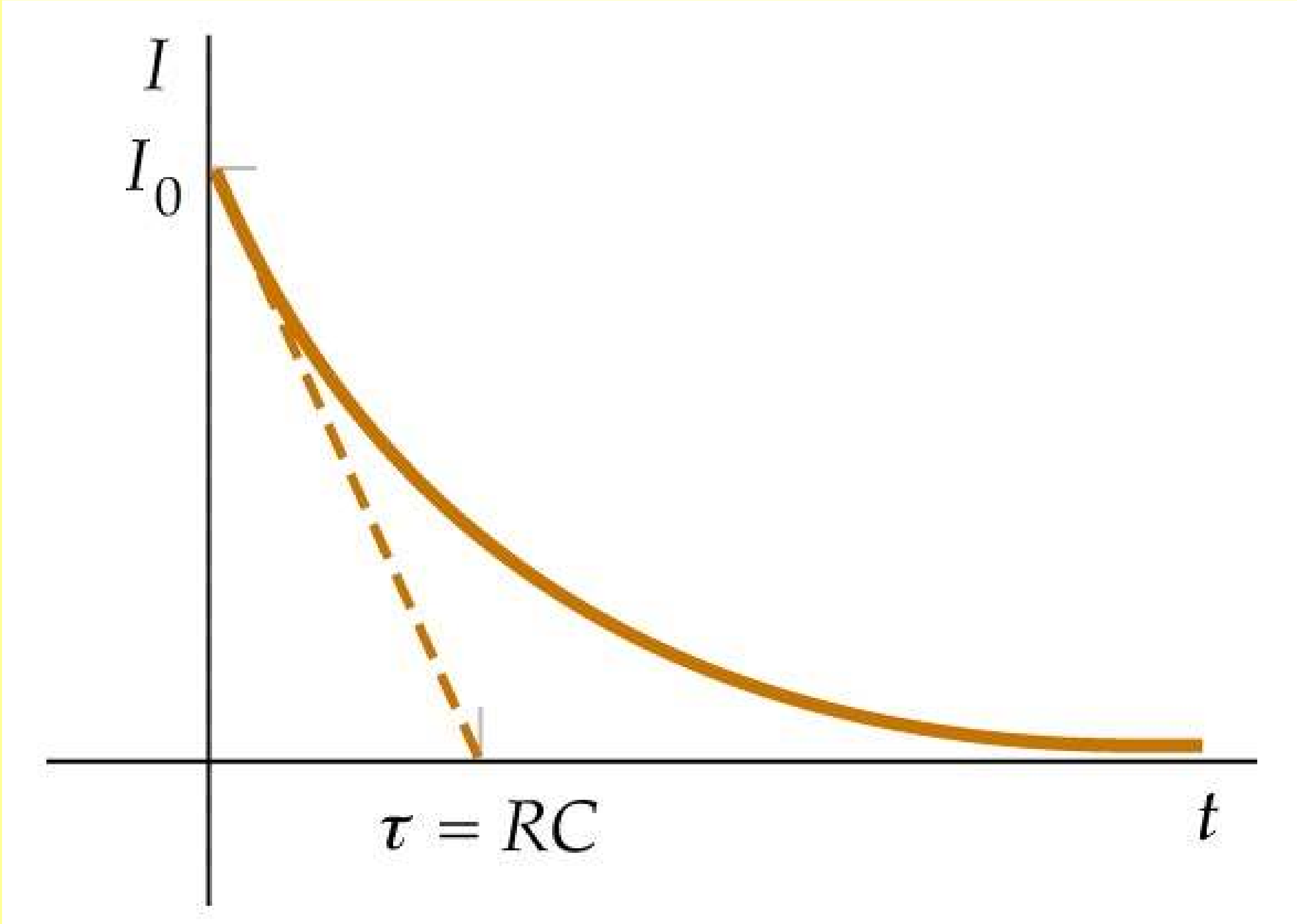
$$I = \left[\frac{CV}{RC} \exp(-\frac{t}{RC})\} \right]$$

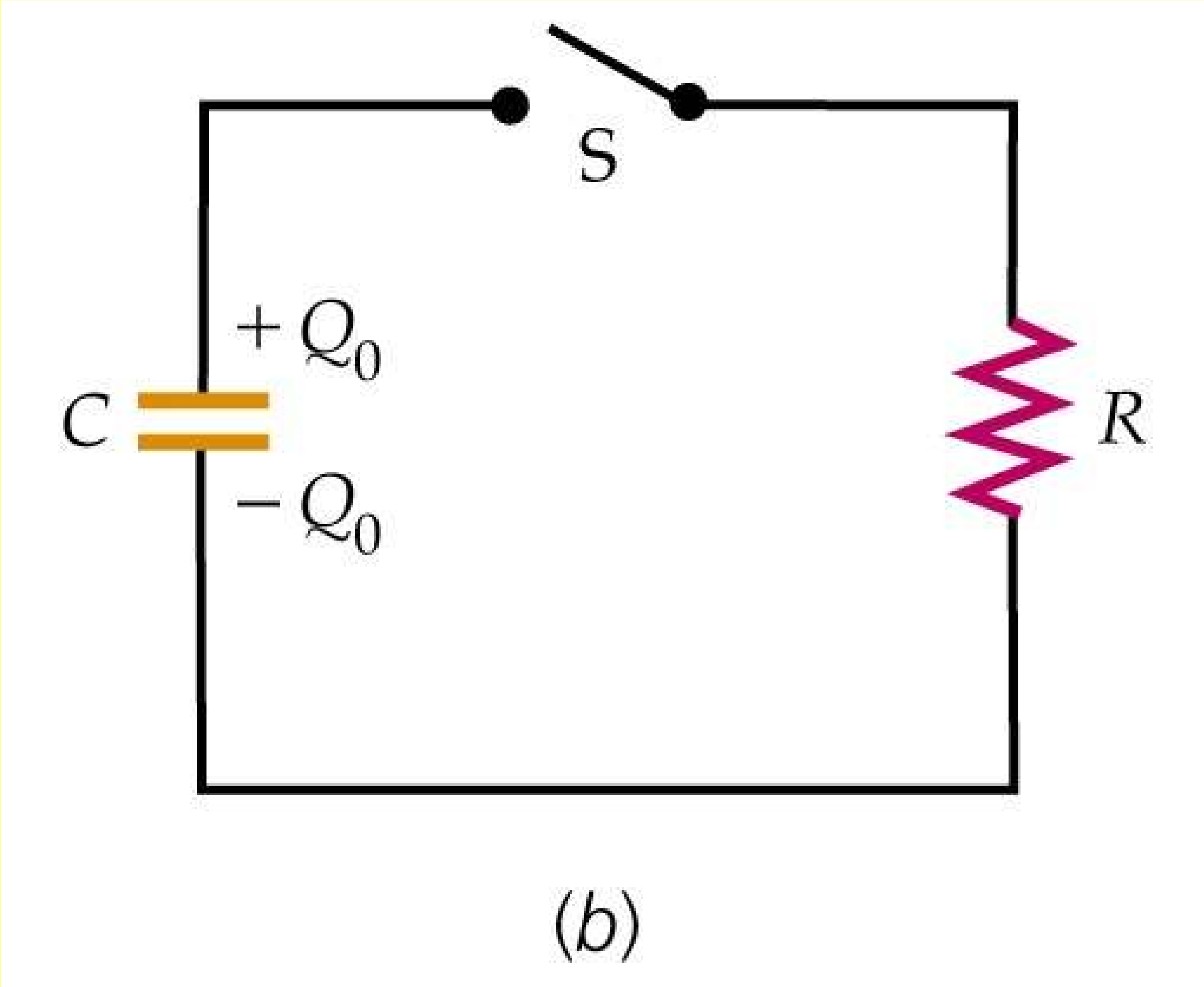
$$t = 0, I = V / R$$

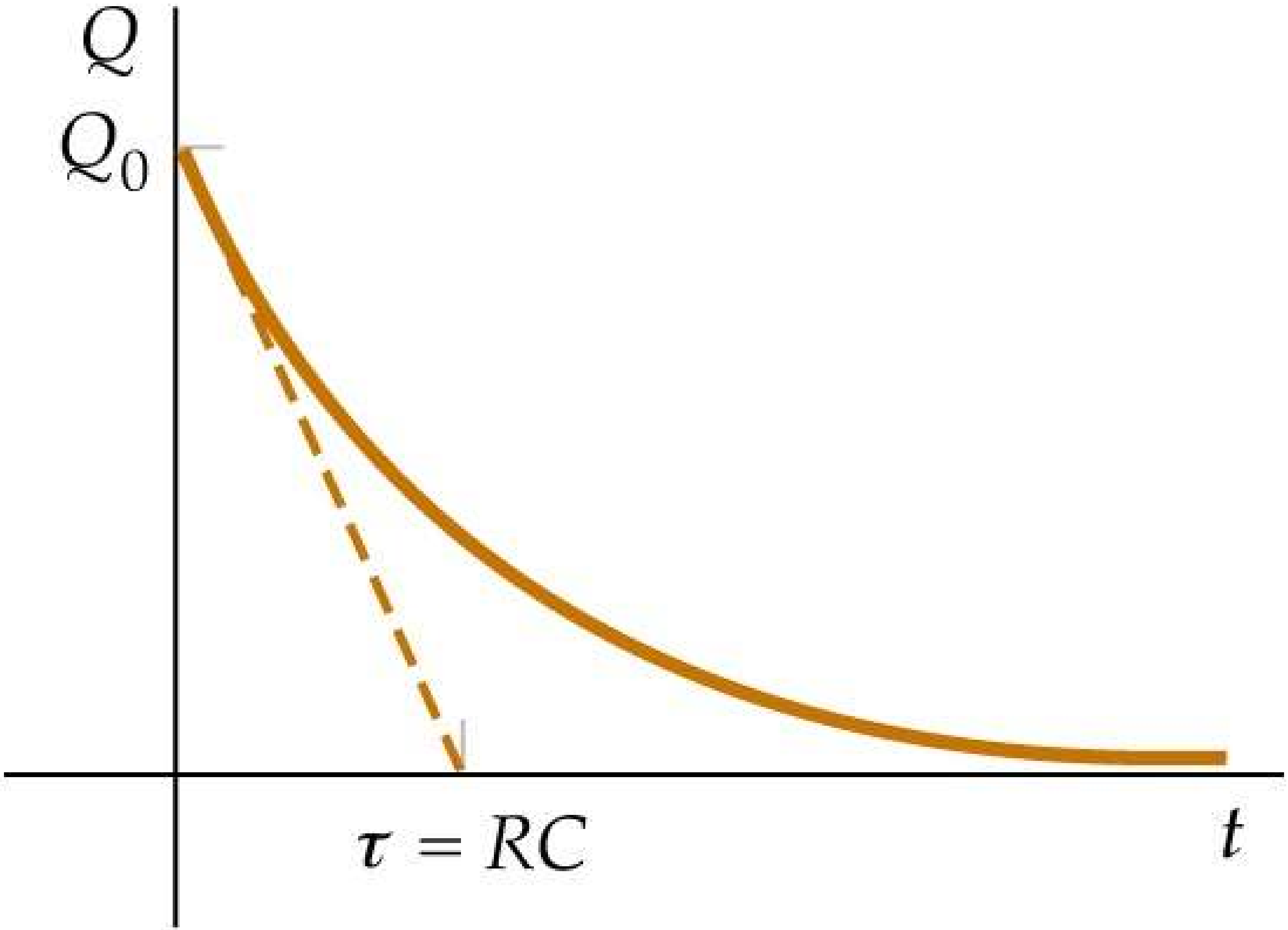

I
I0
I0 = ℰ/R
τ = RC
t

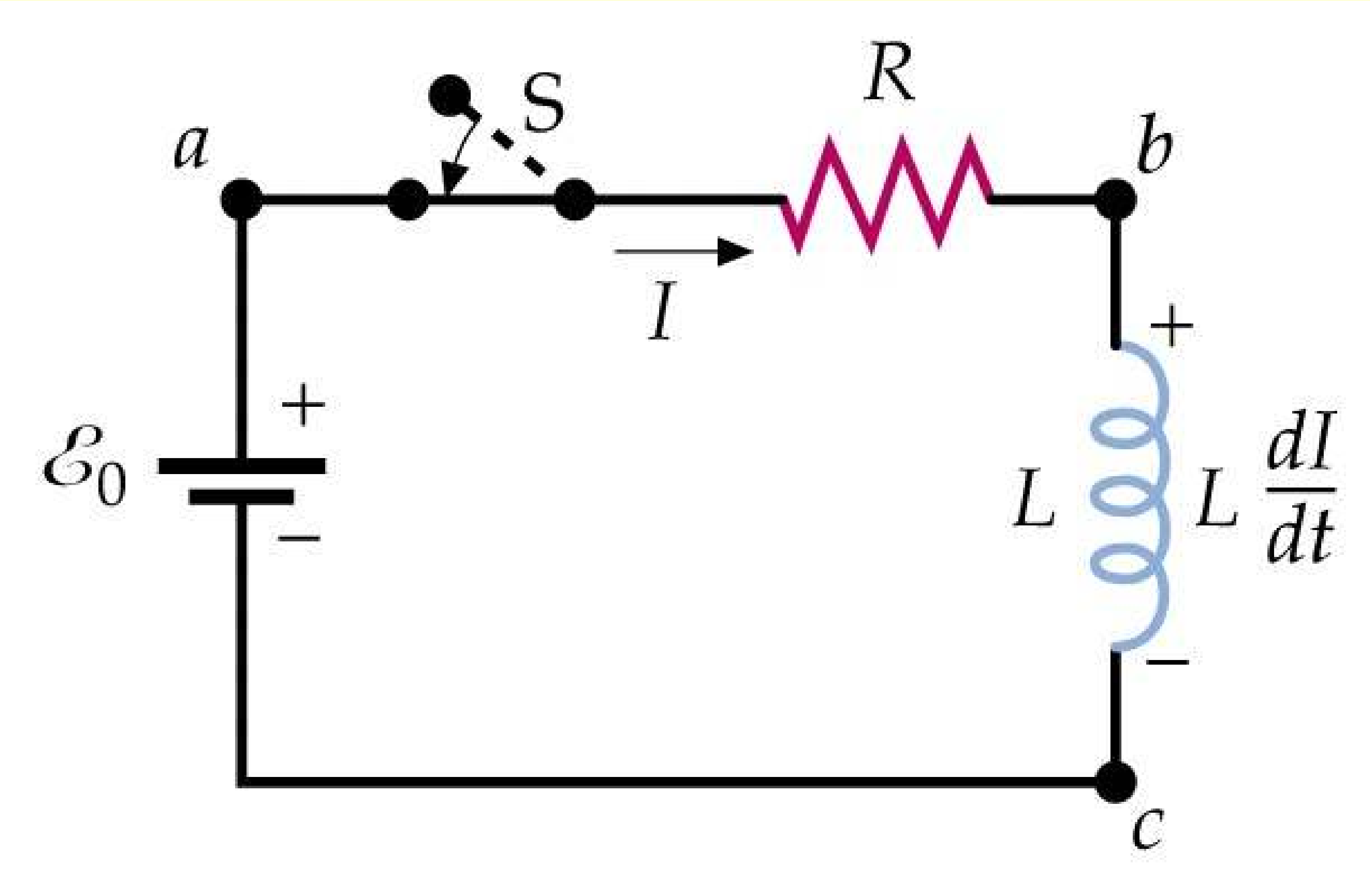


(b)

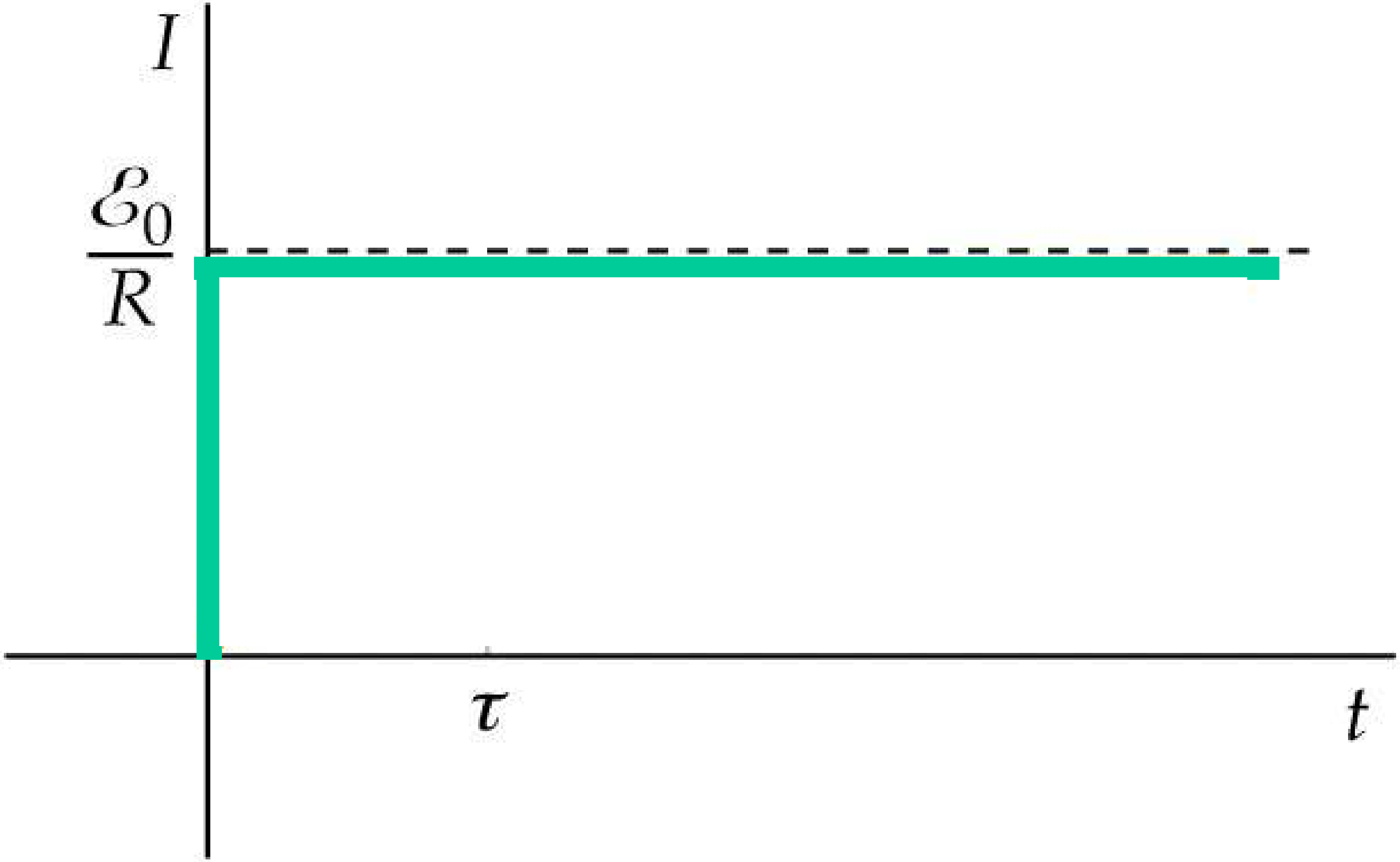

I
I_0
$\tau = RC$
t

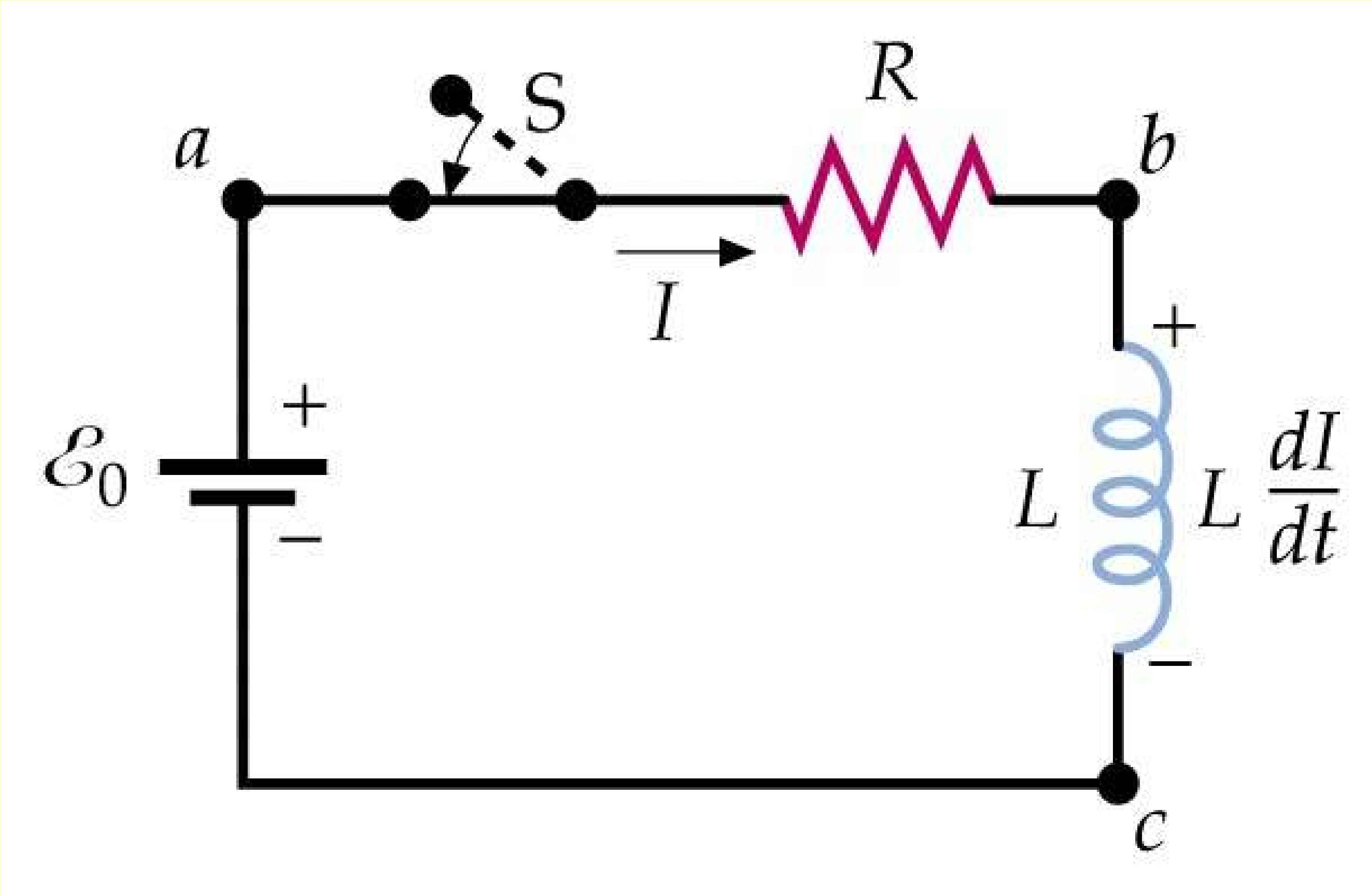

S
+ Q_0
C
− Q_0
R
(b)


Q
Q0
τ = RC
t

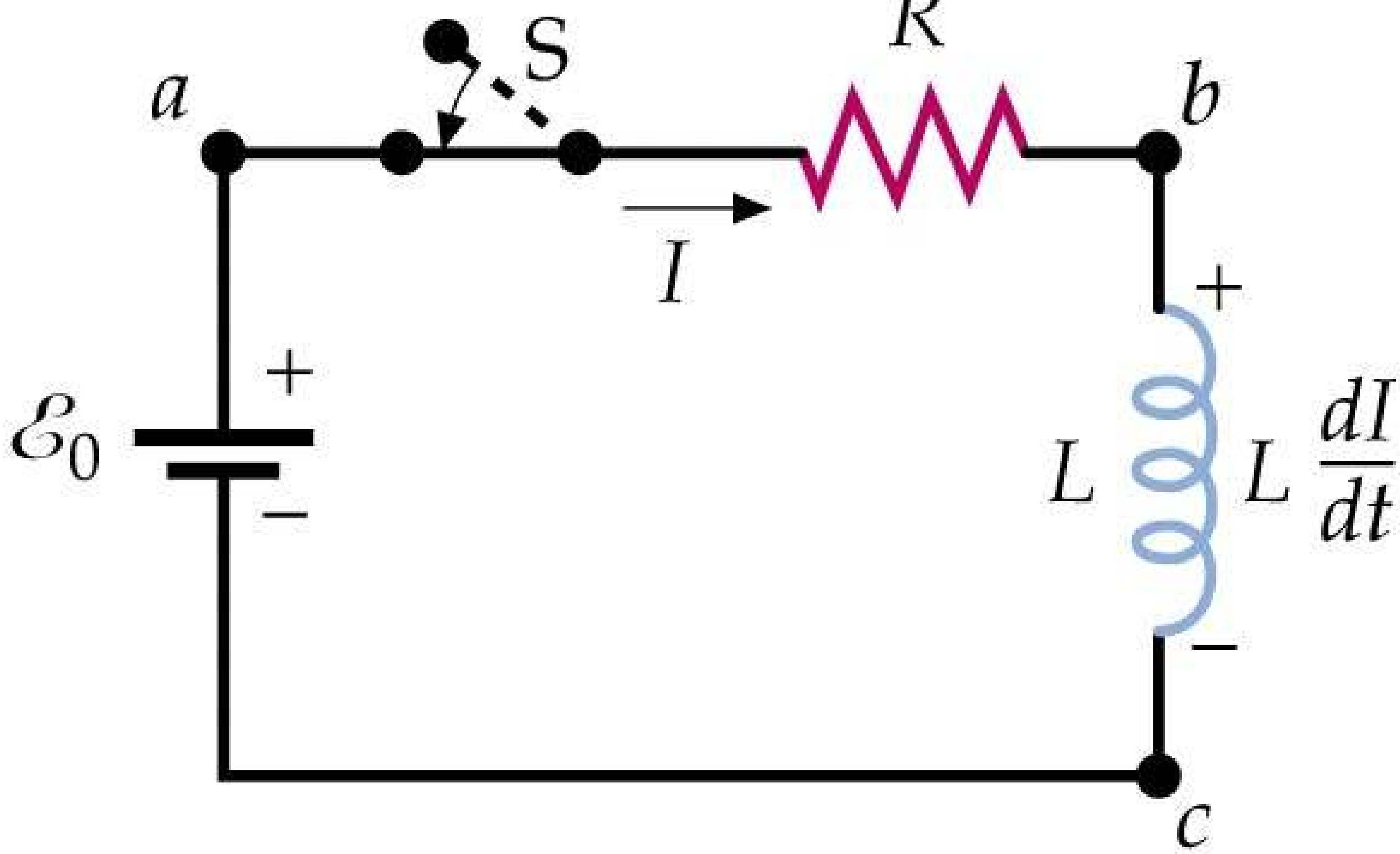


S
R
a
b
I
+
$\mathcal{E}_0$
−
+
L
$L\,\frac{dI}{dt}$
−
c

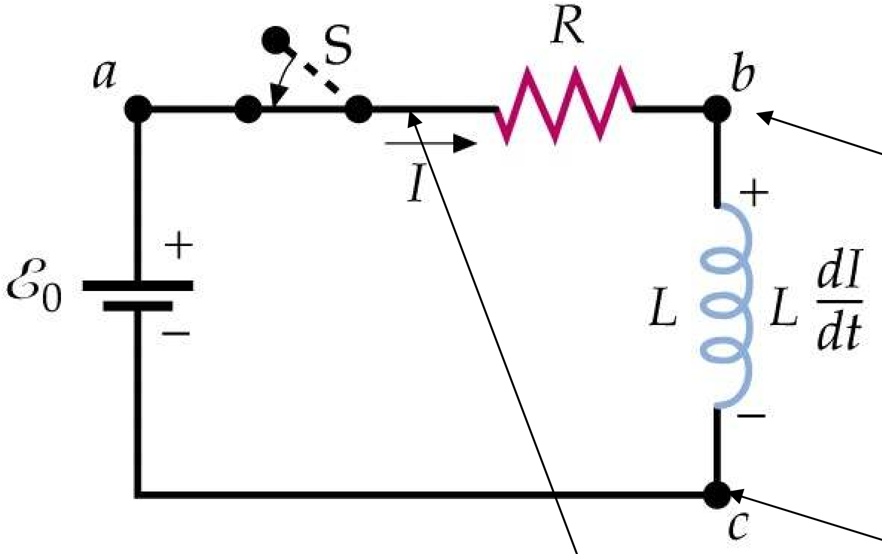

I
ℰ0
R
τ
t



S
R
a
b
I
ℰ0
+
−
L
L dI/dt
+
−
c



S
R
a
b
I
+
−
$\mathcal{E}_0$
L
$L\,\frac{dI}{dt}$
c



$b : L\frac{dI}{dt}$

c：0

a：I・R

$$E_0 = I \cdot R + L\frac{dI}{dt}$$

$$E_0 = I \cdot R + L \frac{dI}{dt}$$

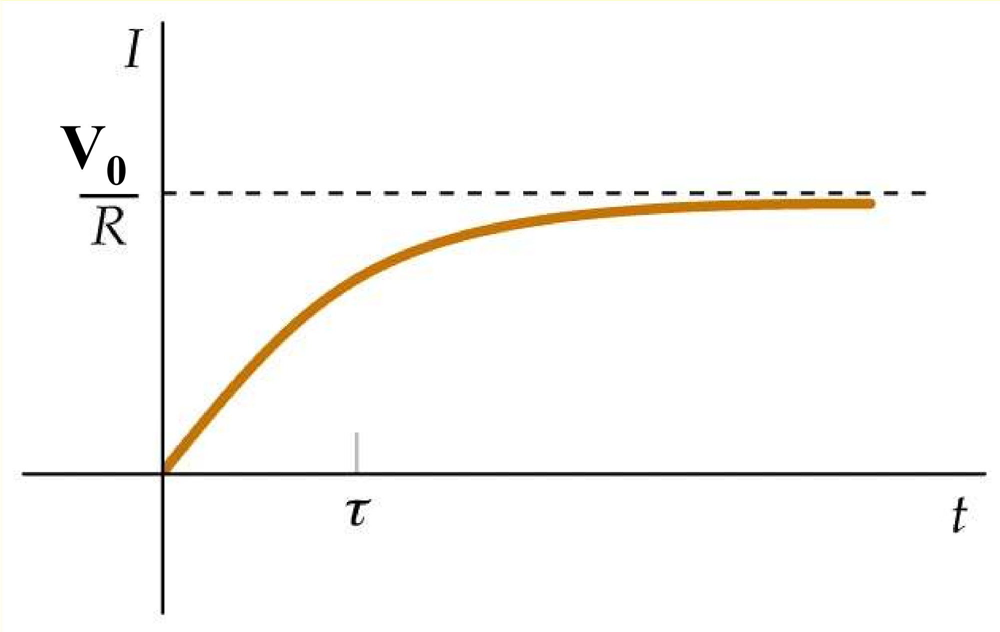
$$X = \left(E \cdot \!\!\!/ \, R \right) - I$$

$$dX = -dI$$

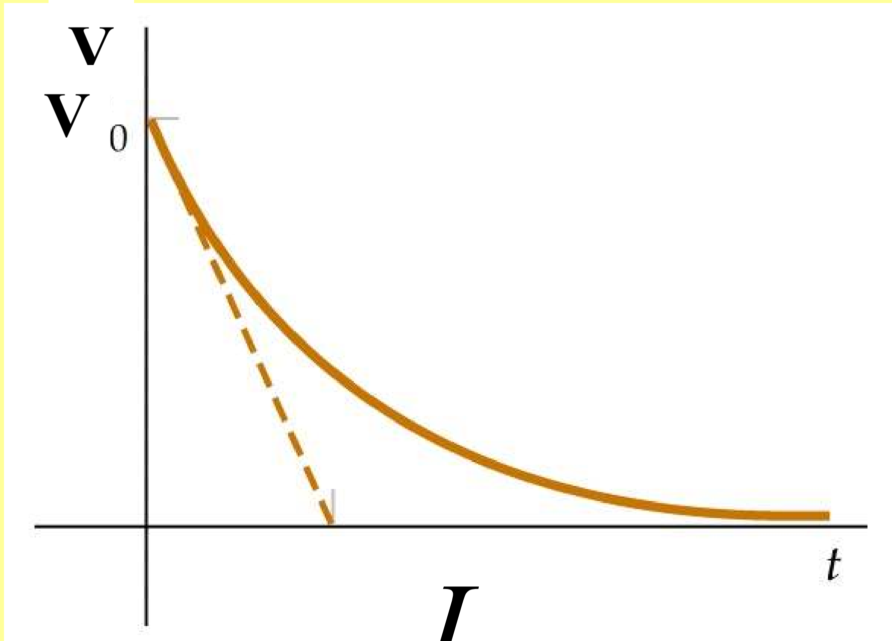
$$I_t = \frac{E}{R}(1 - e^{-\frac{Rt}{L}})$$

$$\tau = \frac{L}{R}$$

コイルに流れる電流の
時間変化

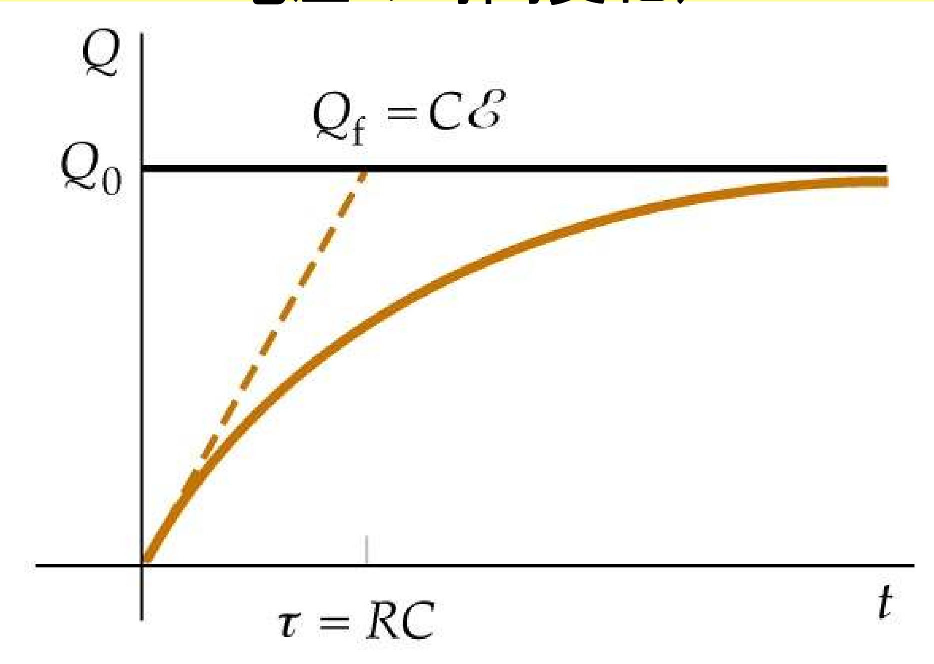


コイルの両端の電圧の
時間変化

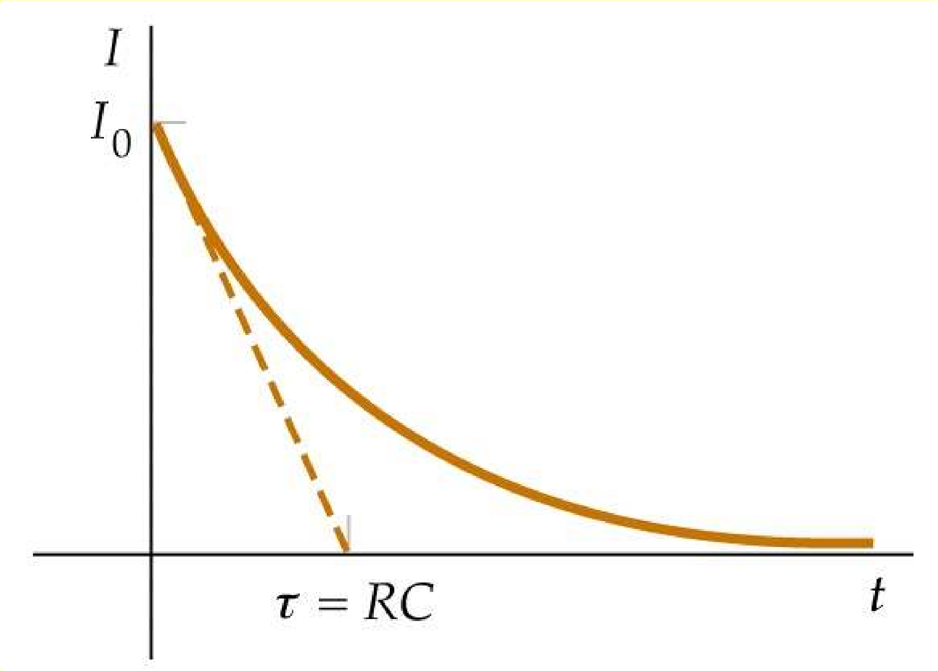


$$\tau = \frac{L}{R}$$

コンデンサに蓄えられる電荷の時間変化
（コンデンサの両端の電圧の時間変化）



電流の時間変化



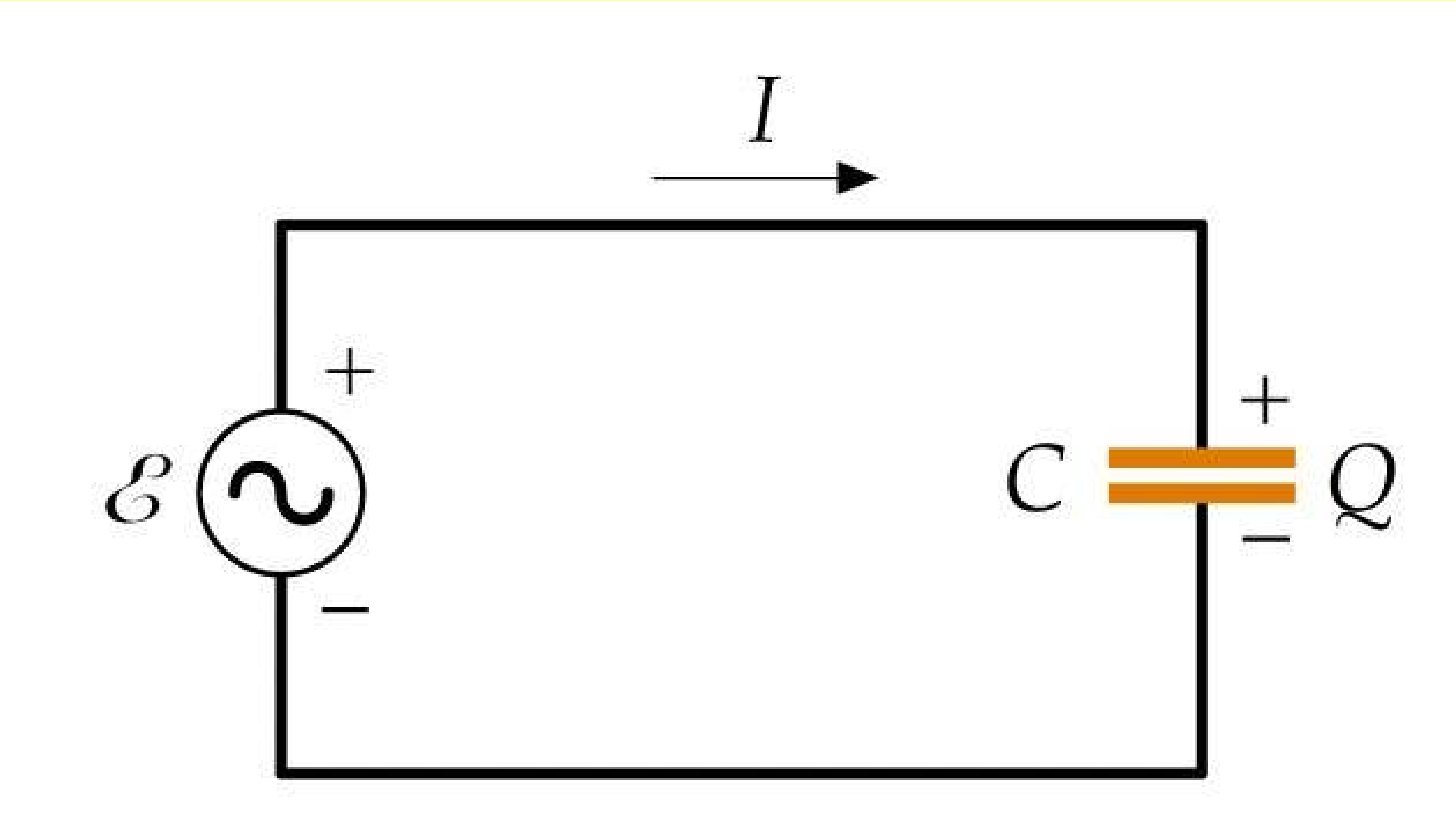
$$Q = CV \qquad N\Phi_m = LI$$

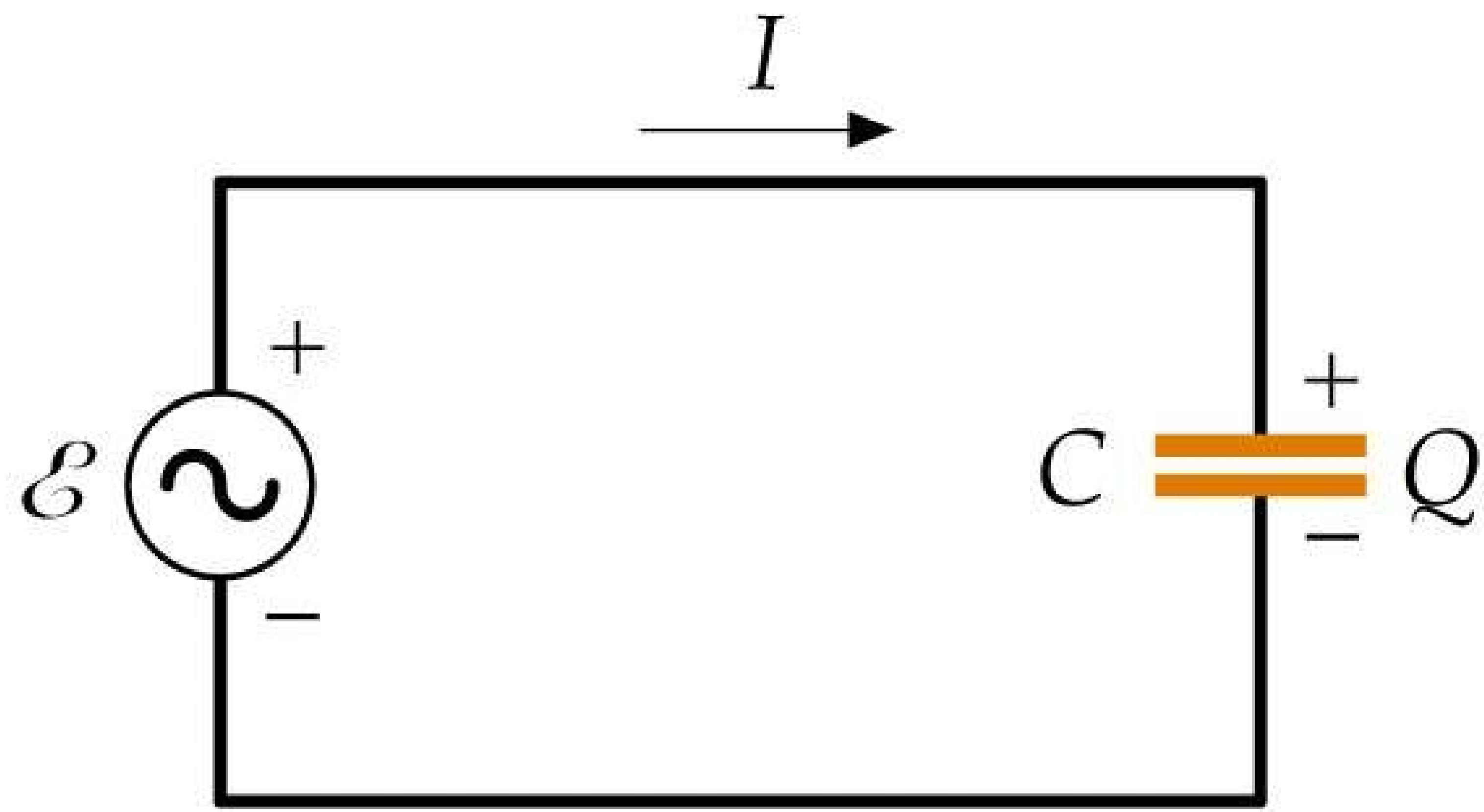
$$\tau = CR \qquad \tau = L / R$$

$$\boxed{I = C\frac{dV}{dt}} \qquad \boxed{V = L\frac{dI}{dt}}$$

$$W = \frac{1}{2}CV^2 \qquad W = \frac{1}{2}LI^2$$

では電気容量を接続した回路では電圧・電流の関係はどうだろう？





$$\varepsilon = Vm \cdot \sin \omega t$$

$$V = Vm \cdot \sin \omega t$$

$$Q = CV$$

$$\frac{d}{dt} Q = I$$

$$I = \frac{dQ}{dt} =$$

$$\omega C \frac{d}{dt}(Vm \sin \omega t)$$

$$= \omega C Vm \cos \omega t$$

電流は電圧を
時間微分した形になる。

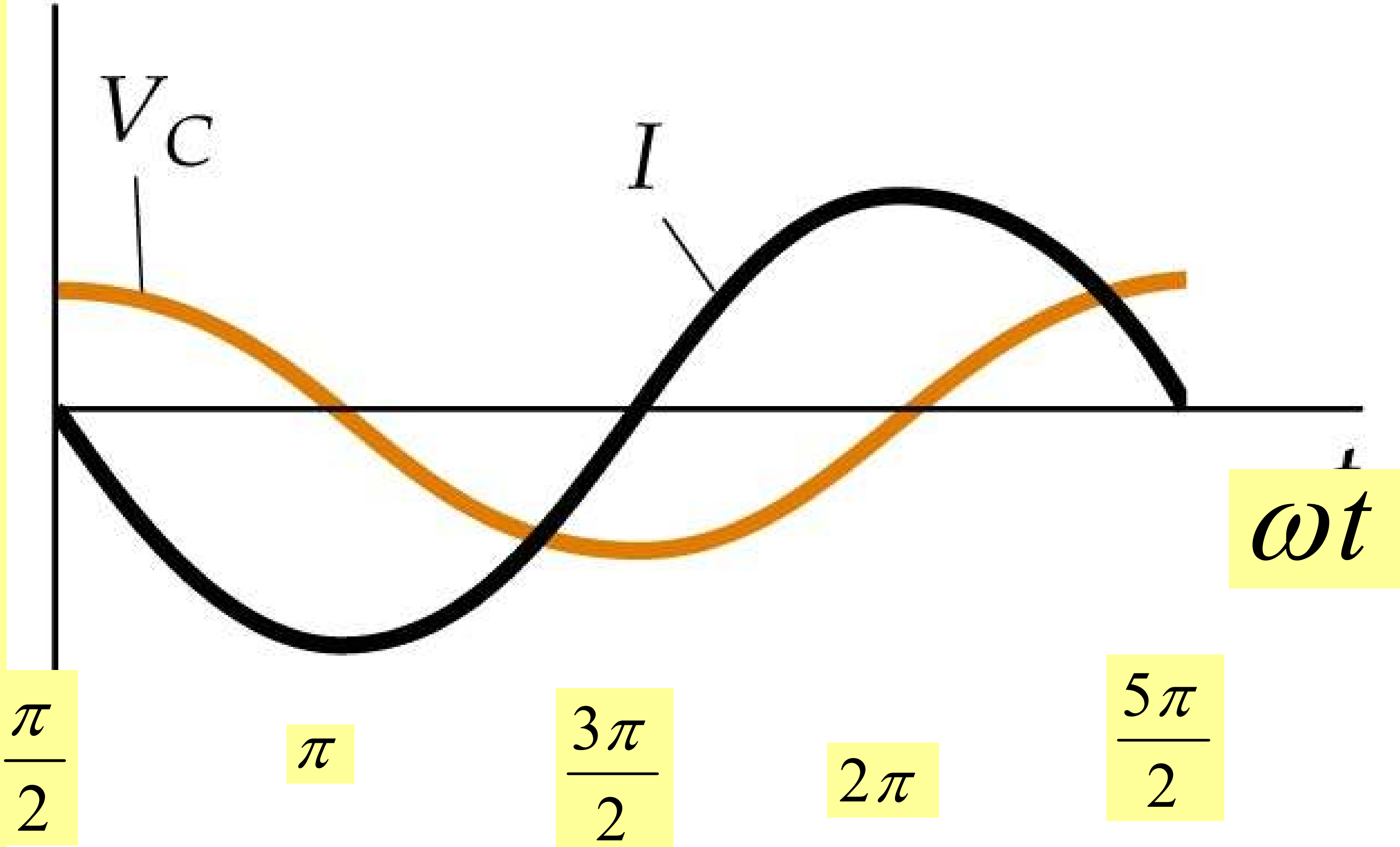
$$V = Vm \cdot \sin \omega t$$

$$I = \omega C Vm \cdot \sin(\omega t + \frac{\pi}{2})$$

$$I = \omega CVm\ \cos \omega t$$

$$= \omega CVm\ \sin(\omega t + \frac{\pi}{2})$$

電流は電圧に対してπ /2だけ位相がずれて進んだ波になっている。



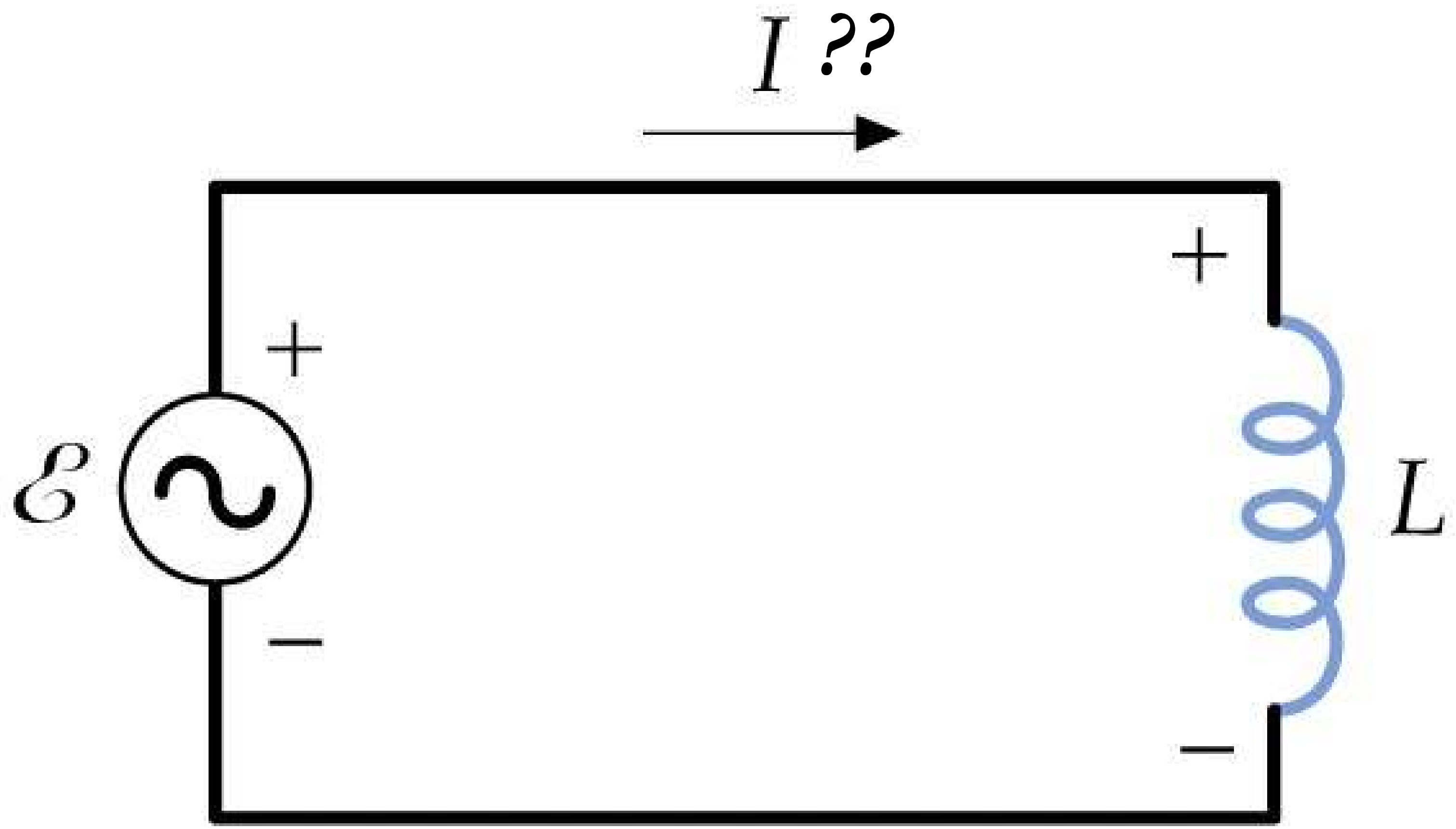
V_C
I
ωt
$\frac{\pi}{2}$
π
$\frac{3\pi}{2}$
2π
$\frac{5\pi}{2}$

$$Im = \omega C V m \qquad I = \frac{V}{R}$$

オームの法則に対してRの対応を見ると

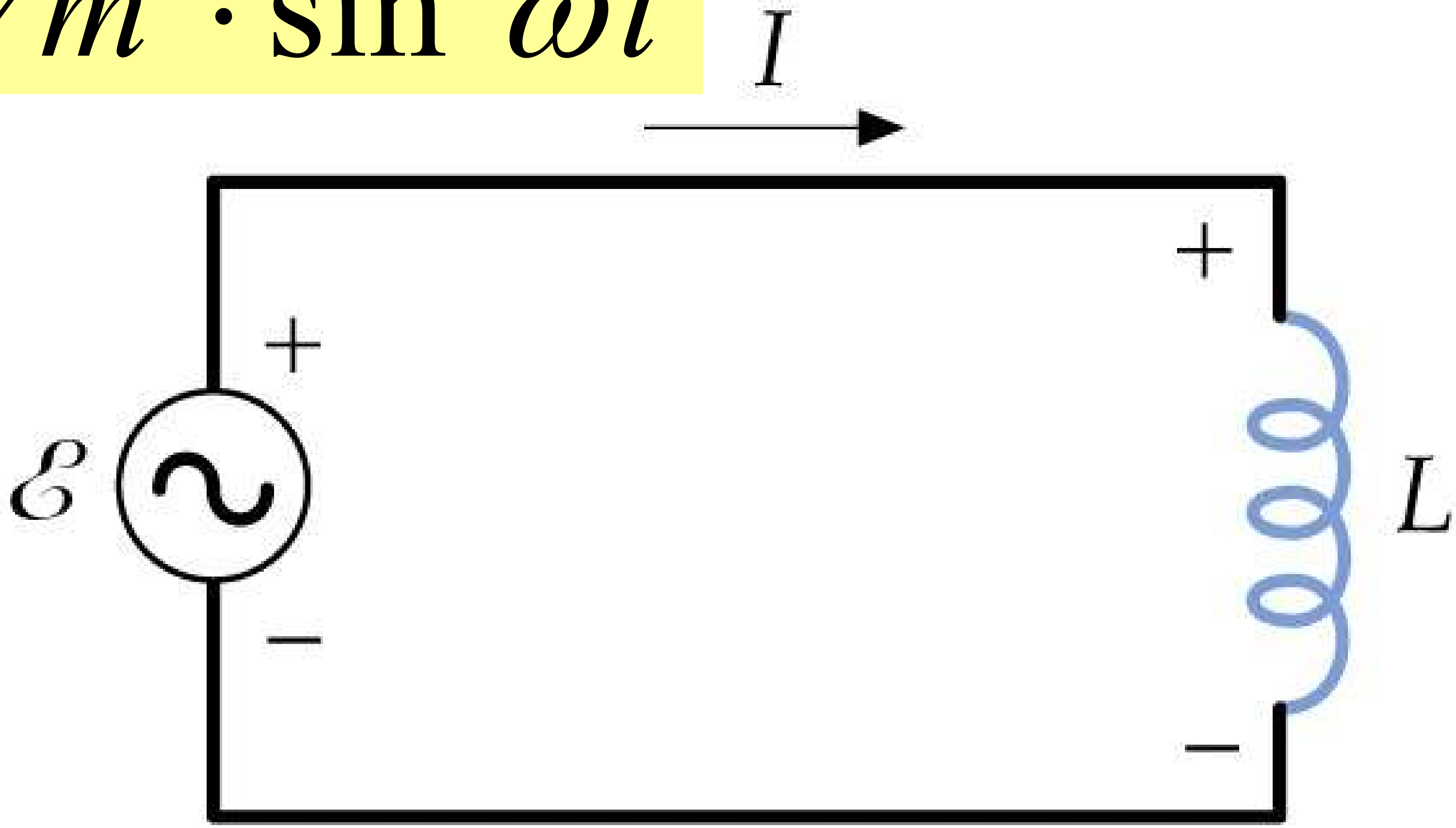
$$R \rightarrow 1/\omega C \qquad X_C = 1/\omega C$$

誘導素子を接続するとどのようか？



$$\varepsilon = Vm \cdot \sin \omega t$$

$$\varepsilon = Vm \cdot \sin \omega t$$



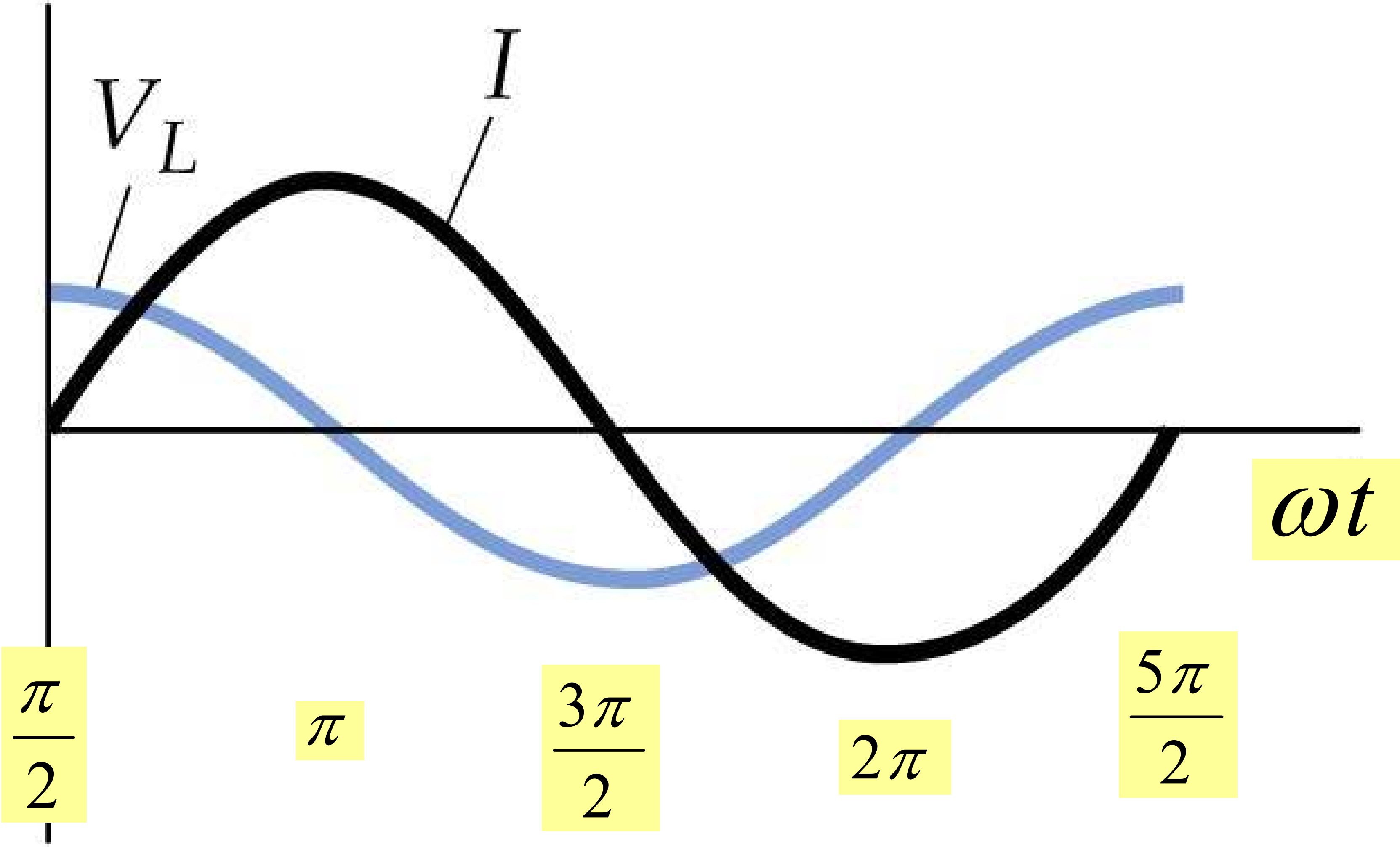
$$\varepsilon - L \frac{dI}{dt} = 0$$

$$L\frac{dI}{dt} = Vm \cdot \sin \omega t$$

$$I = \frac{Vm}{L}\int \sin\ \omega t \cdot dt$$

$$= -\frac{Vm}{\omega L}\cos\ \omega t$$

電流は電圧を
時間積分した形になる。



V_L
I
ωt
$\frac{\pi}{2}$
π
$\frac{3\pi}{2}$
2π
$\frac{5\pi}{2}$

$$I = -\frac{Vm}{\omega L}\cos \omega t$$

$$= \frac{Vm}{\omega L}\sin(\omega t - \frac{\pi}{2})$$

電流は電圧に対してπ /2だけ位相がずれて遅れた波になっている。

$$V = Vm \cdot \sin \omega t$$

$$I = \frac{Vm}{\omega L} \sin(\omega t - \frac{\pi}{2})$$

$$Im = \frac{Vm}{\omega L}$$

$$I = \frac{V}{R}$$

オームの法則に対してRの対応を見ると

$$R \rightarrow \omega L$$

$$X_L = \omega L$$