物理学概論

東海大学　理学部
物理学科

TOKAI

Department of Physics School of Science
Tokai University

本日のメニュー

1. 電場（電界）と電位の関係

2. ガウスの法則と電気容量

今日のポイント

- 電界と電位の関係
- ガウスの法則

$$\varepsilon \oint \boldsymbol{E} \cdot \boldsymbol{ds} = \mathrm{Q}$$

$$V = -\int \boldsymbol{E} \cdot \boldsymbol{dr}$$

物体に力を及ぼす例

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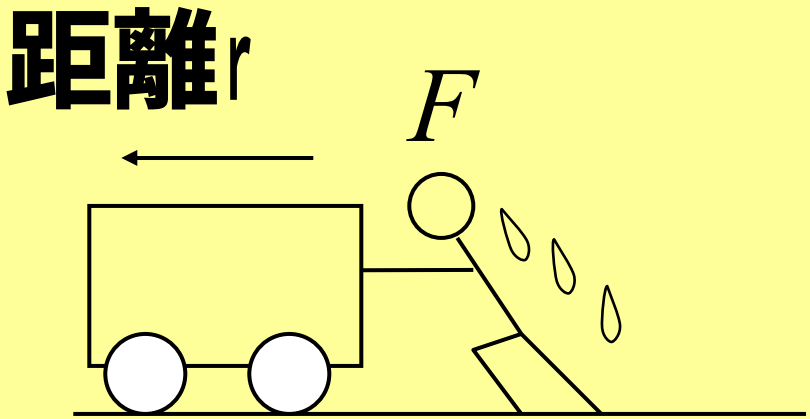
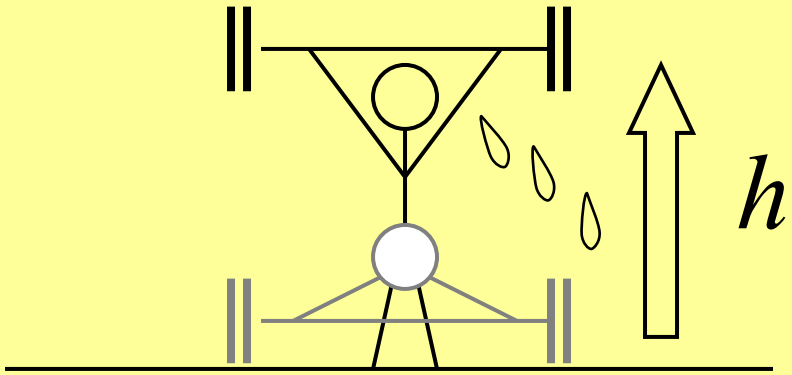


$$U = \int \boldsymbol{F} \cdot \boldsymbol{dr}$$

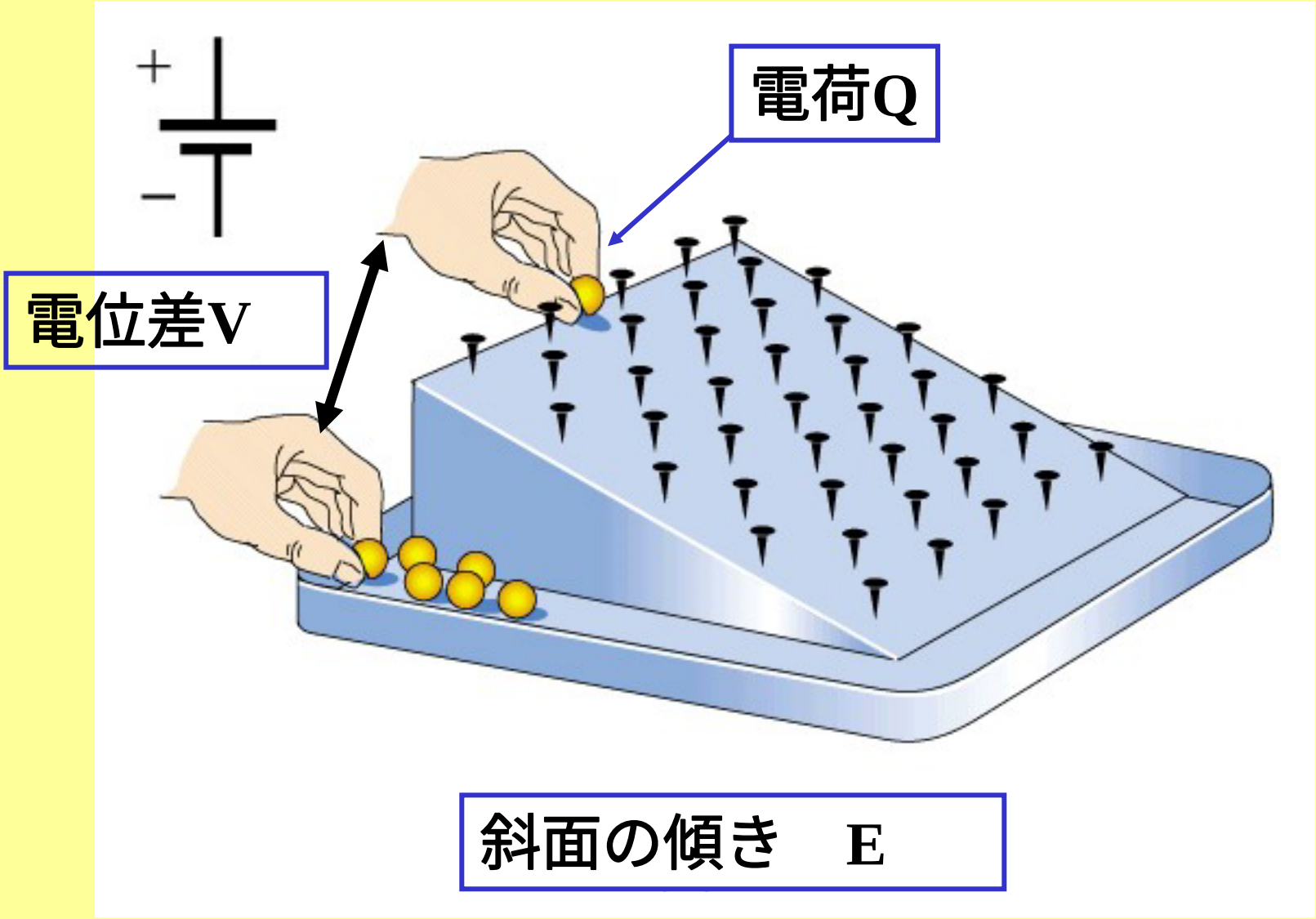
$$= Fr$$

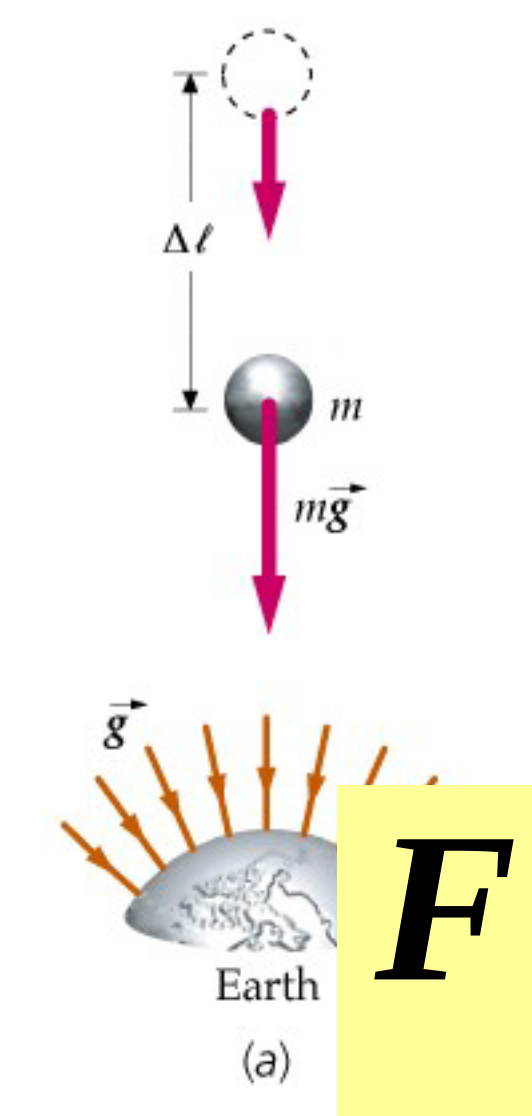
仕事をする



$$U = -\int \boldsymbol{F} \cdot \boldsymbol{dr}$$

$$= -(-mgh)$$


+
−
電荷Q
電位差V
斜面の傾き　E



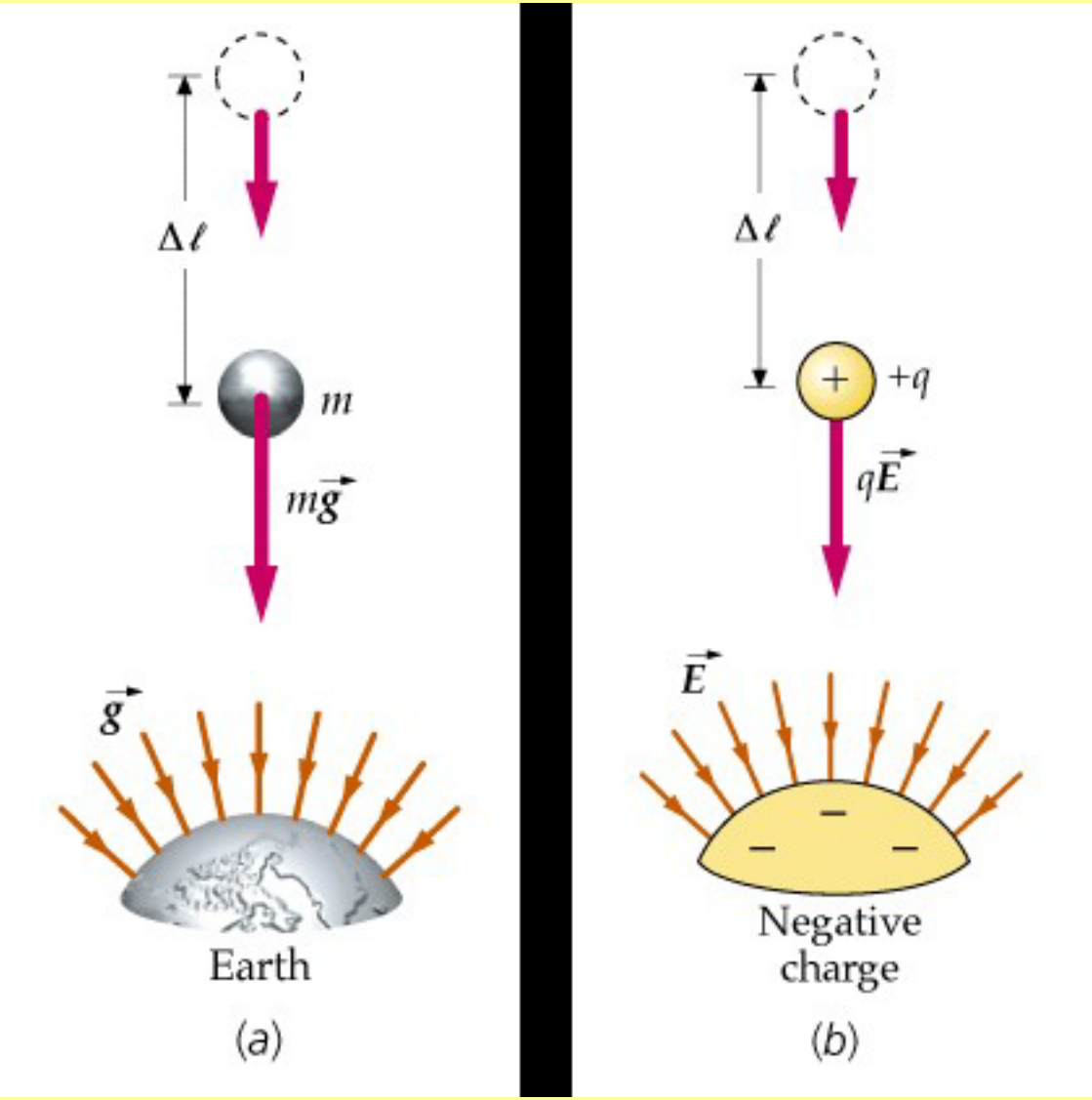
$$U = \int \mathbf{F} \cdot \mathbf{dr}$$

$$= mgh$$

$$\boldsymbol{F} = -gradU$$

$$= -m\boldsymbol{g}$$

$$F = -\frac{dU}{dr}$$

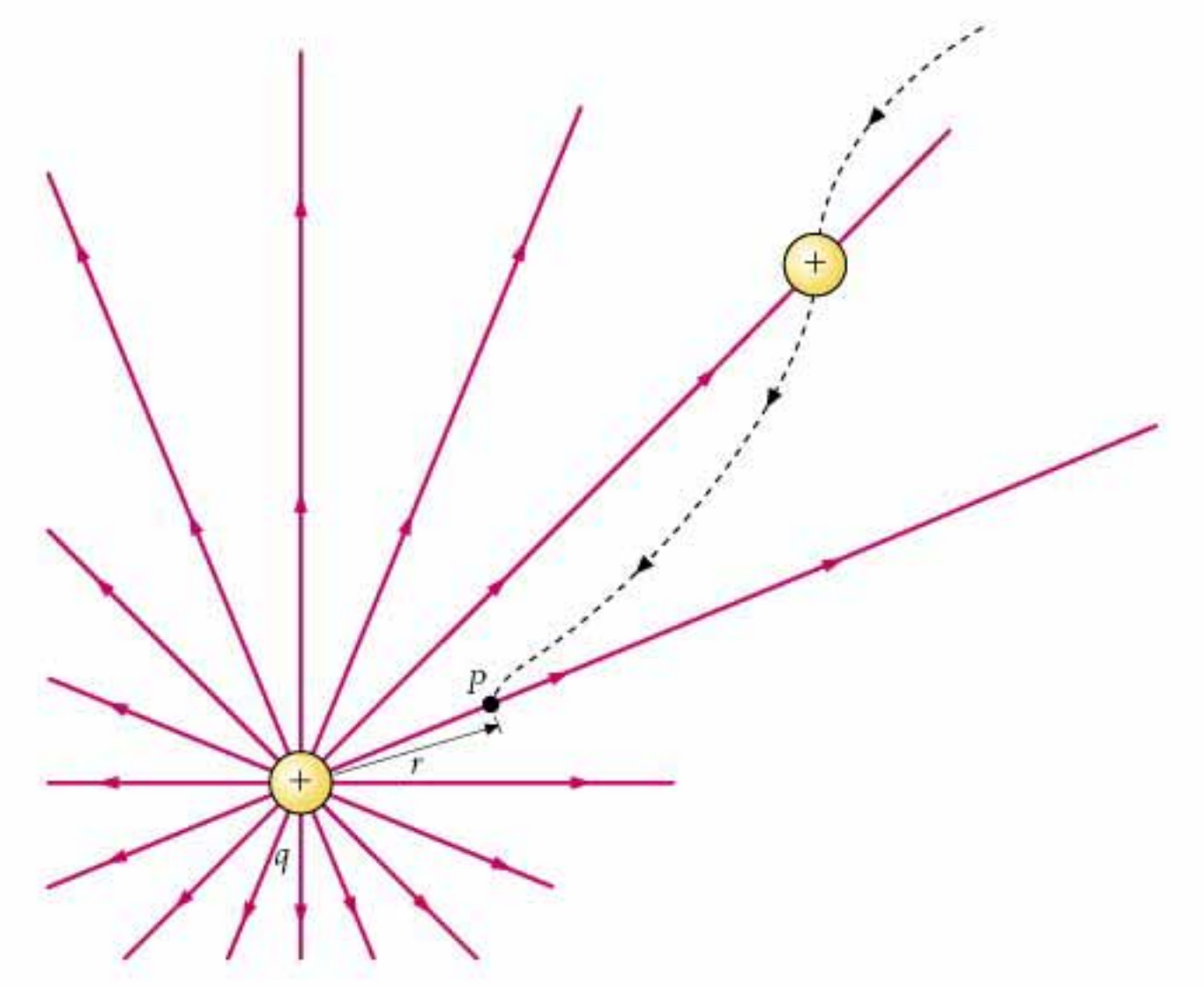

$\Delta\ell$
m
$m\vec{g}$
$\vec{g}$
Earth
(a)
$\Delta\ell$
$+q$
$q\vec{E}$
$\vec{E}$
Negative charge
(b)

$$U = -\int_{r_0}^{r} \boldsymbol{F} \cdot \boldsymbol{dr}$$

$$\boldsymbol{F} = Q \cdot \boldsymbol{E}$$

$$\phi = -\int_{r_0}^{r} \boldsymbol{E} \cdot \boldsymbol{dr}$$

$$V$$


P
r
q

$$\phi = -\int_{r_0}^{r} \boldsymbol{E} \cdot \boldsymbol{dr}$$

$$E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$$

$$\phi = -\int_{r_0}^{r} \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2} dr$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

$$V = -\int_{r_0}^{r} \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}dr$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{r}\right]_{\infty}^{r}$$

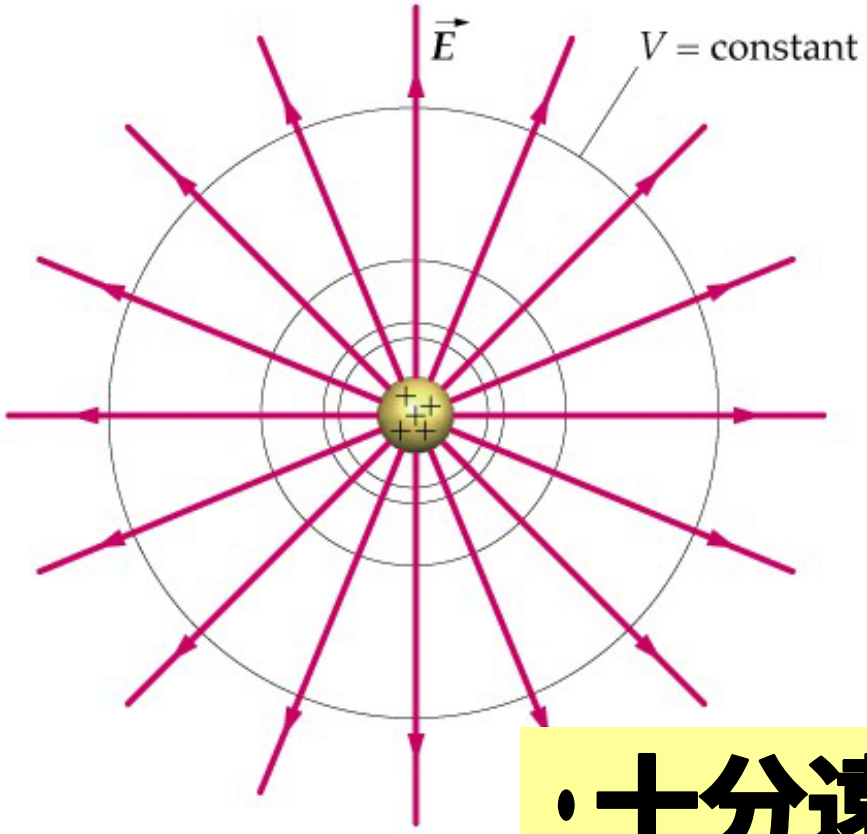
斜面の傾斜の度合い

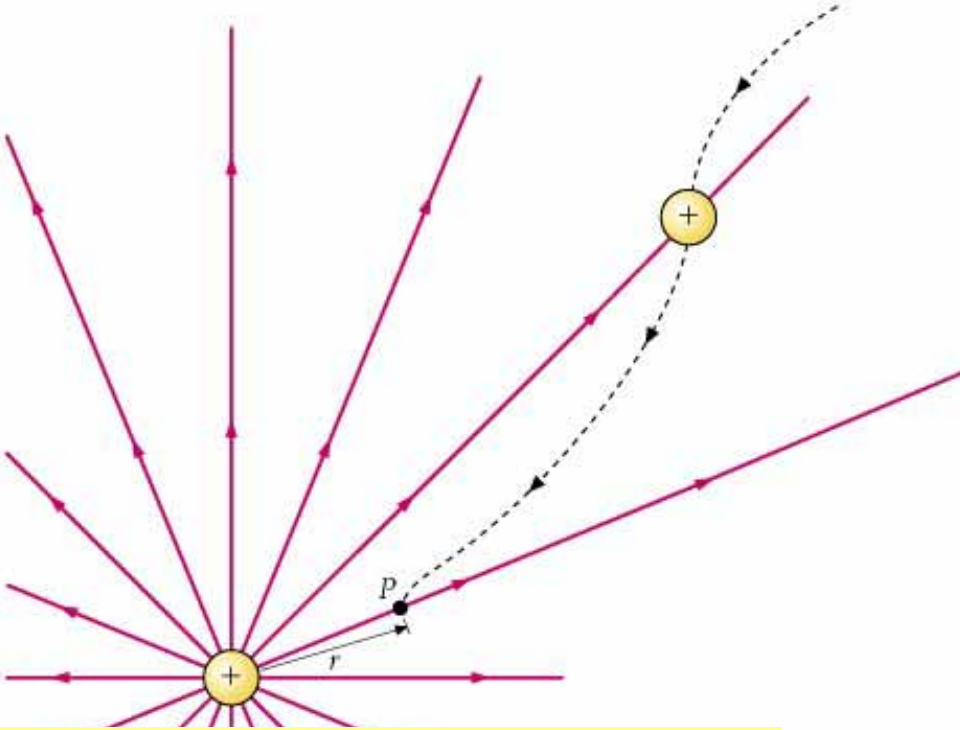
$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q'}{r^2}$$

一階の積分 ⬇ ⬆ 一階の微分

山の高さ

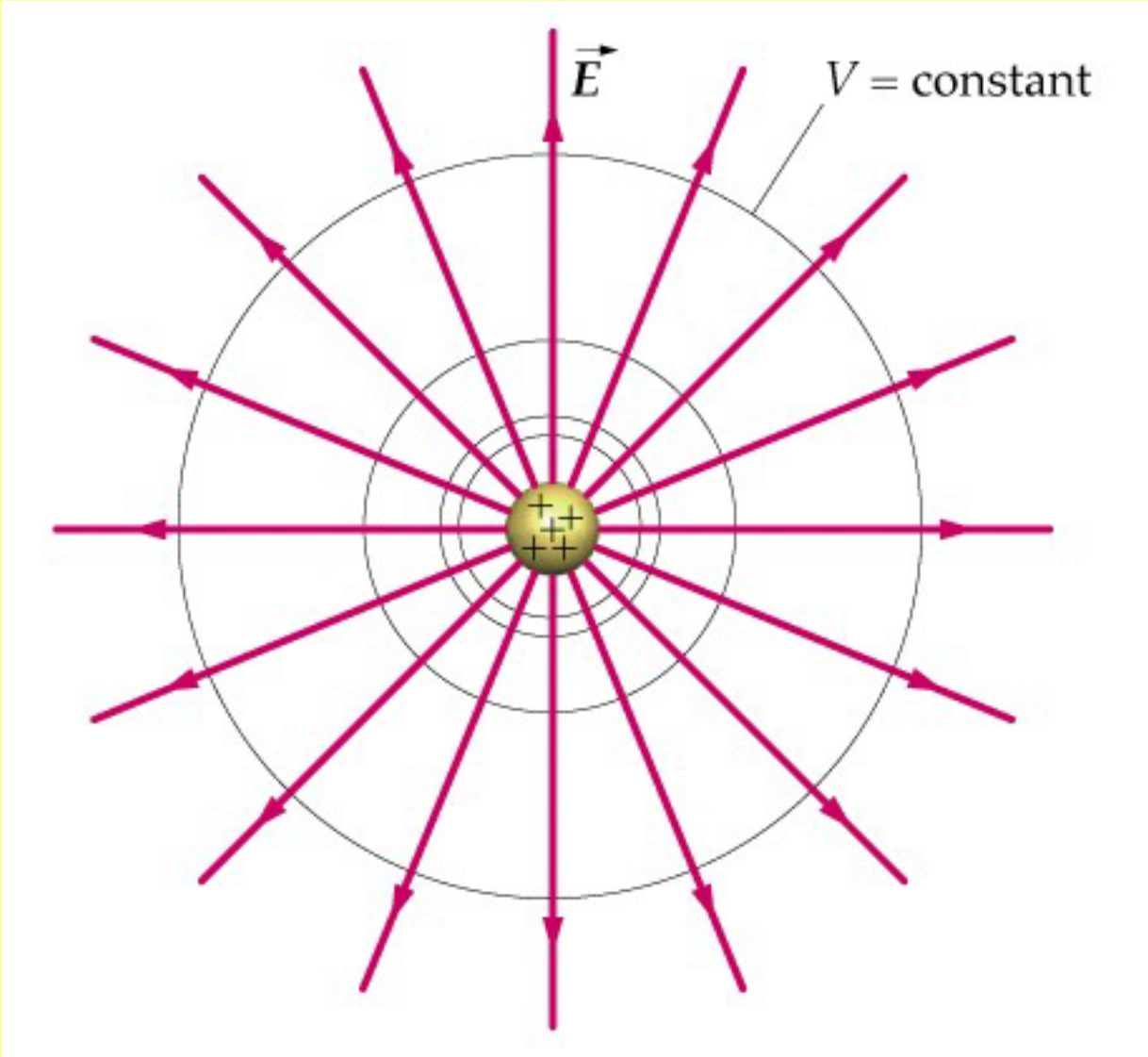
$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q'}{r}$$

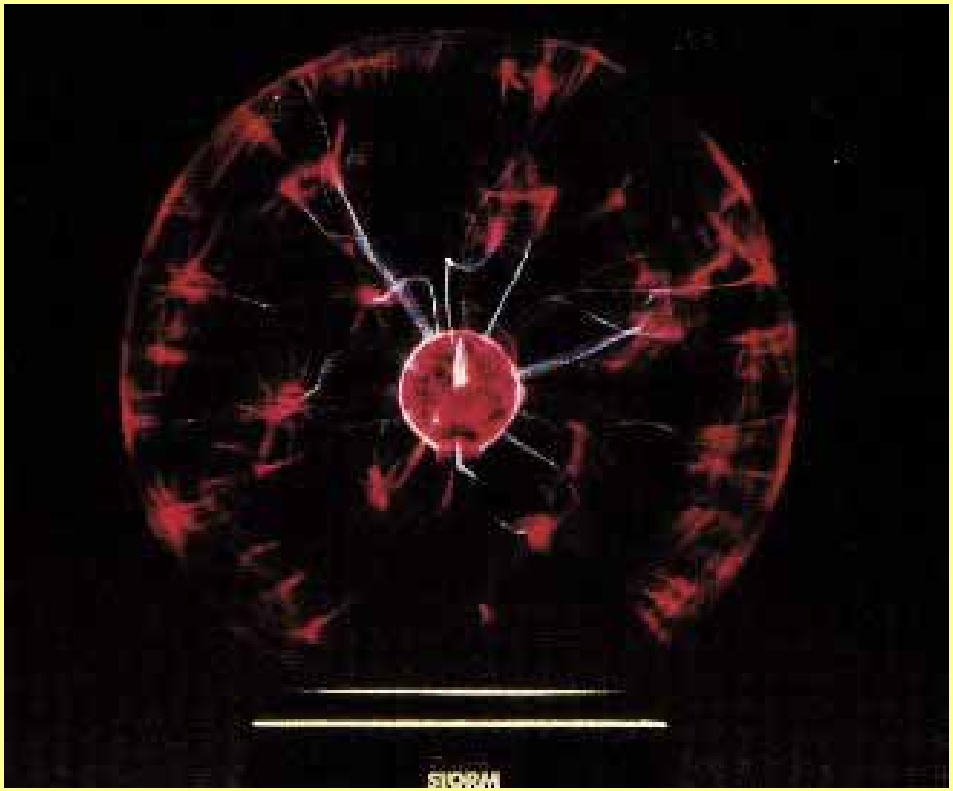




・十分遠くから電荷を運ぶ
・基準点が必要

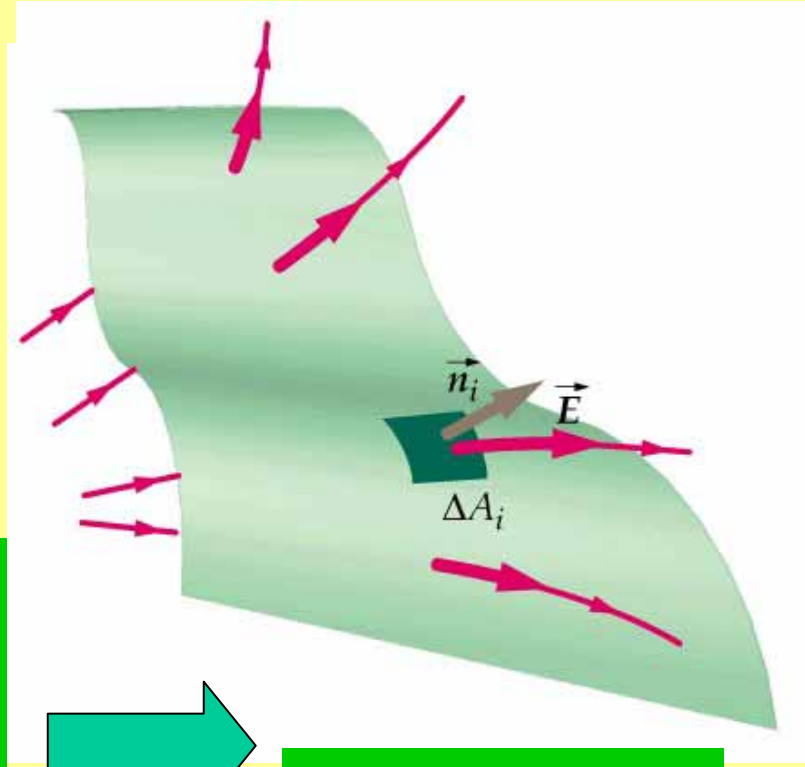
$$V = -\int E \cdot dr$$


$\vec{E}$
V = constant



$$\varepsilon \oint \boldsymbol{E} \cdot \boldsymbol{ds} = Q$$

電界がある平面
を垂直に貫いて
湧き出している



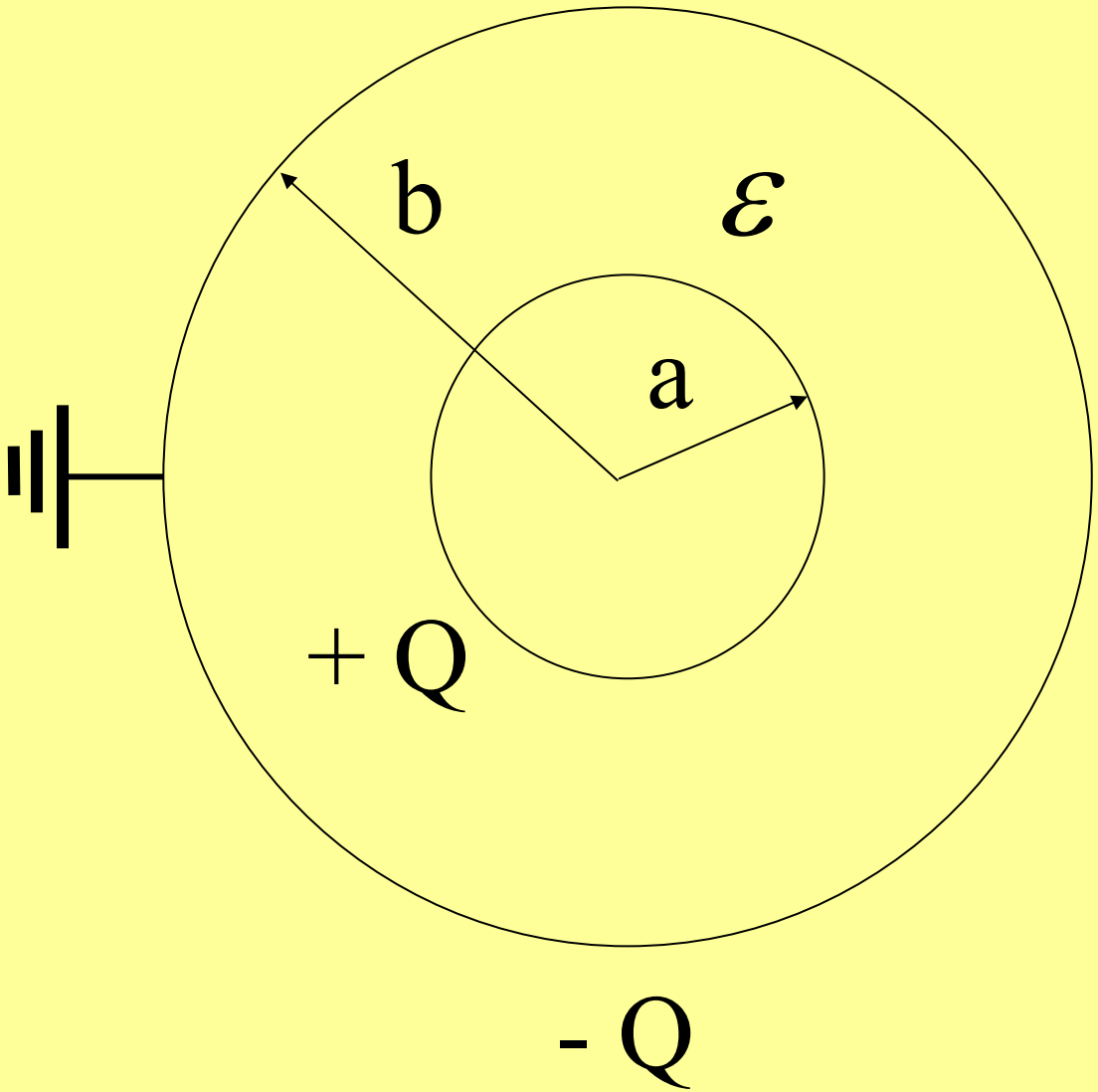
電界の力線が有効に閉
局面を貫く総本数

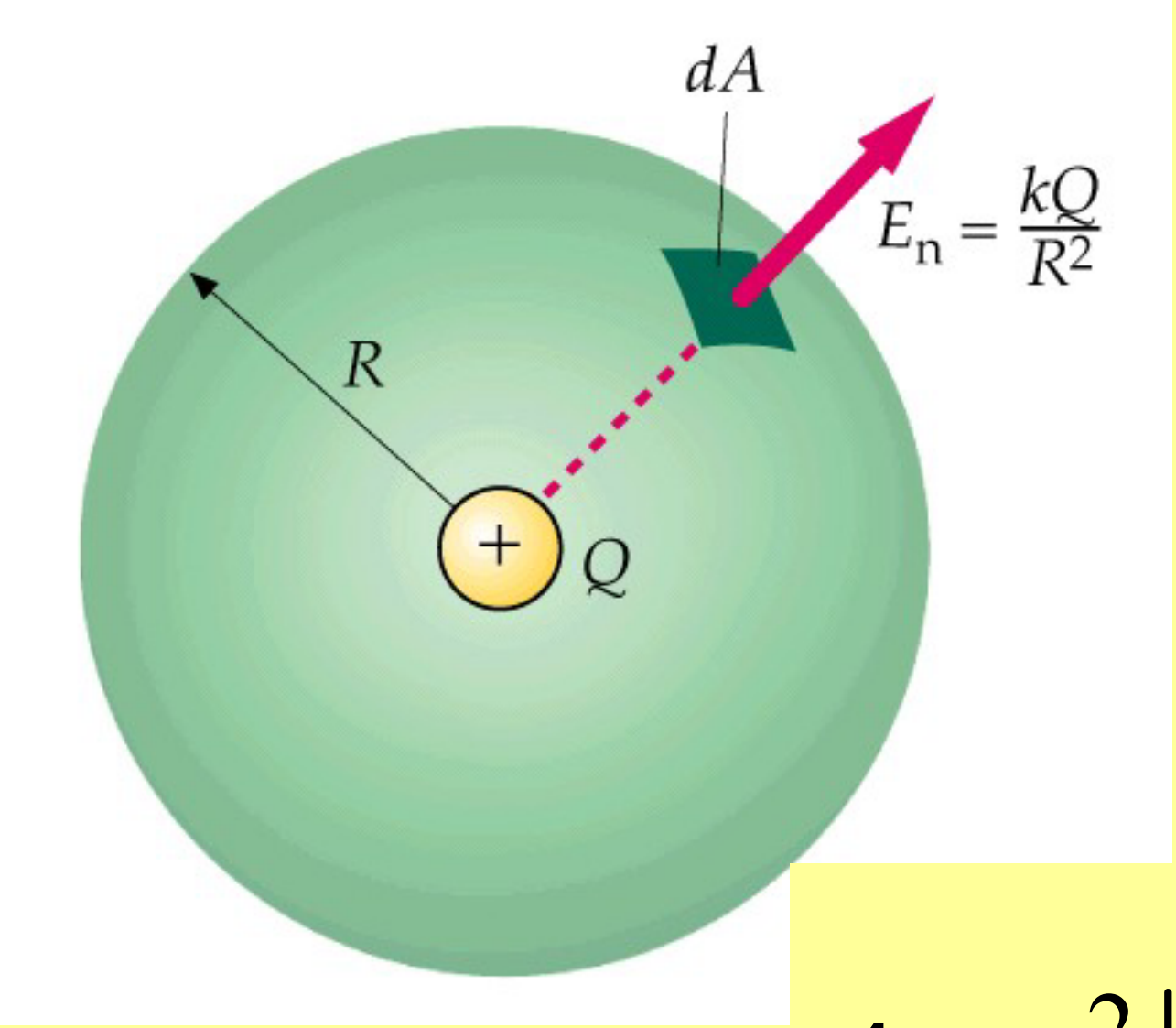
閉局面内
の電荷

$$\varepsilon \oint \boldsymbol{E} \cdot \boldsymbol{ds} = Q$$

$$V = -\int \boldsymbol{E} \cdot \boldsymbol{dr}$$

$$Q = C\ V$$

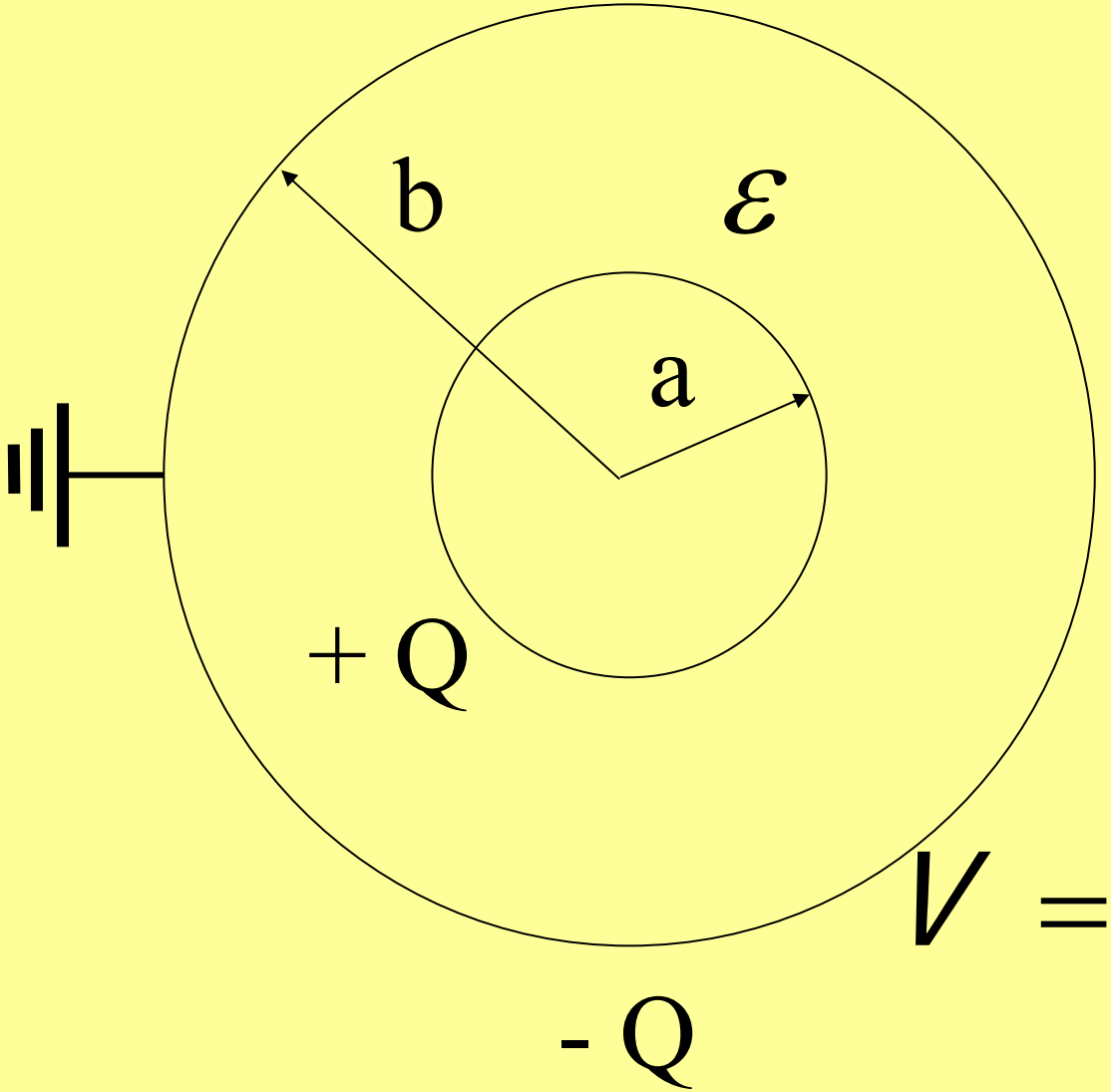

b
ε
a
+ Q
- Q



$$\underline{4\pi r^2}\,|\boldsymbol{E}| = \frac{Q}{\varepsilon}$$

球の表面積

$$V_b - V_a = -\int_a^b E \cdot dr = -\frac{1}{4\pi\varepsilon}\int_a^b \frac{dr}{r^2}$$



$$V = \frac{1}{4\pi\varepsilon} \cdot \frac{b-a}{ab} \cdot Q$$

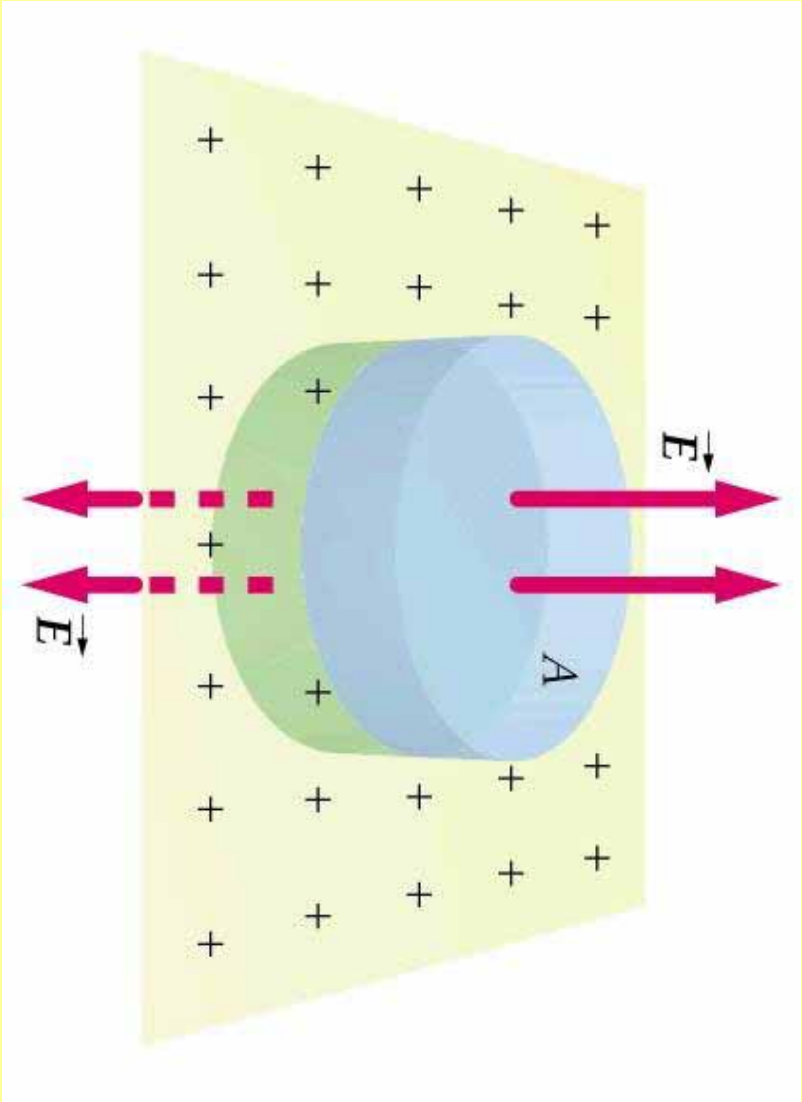
$$V = \frac{1}{4\pi\varepsilon} \cdot \frac{b-a}{ab} \cdot Q$$

$$C = 4\pi\varepsilon \frac{ab}{b-a}$$

$b \to \infty$ の孤立した球では

$$C = 4\pi\varepsilon a$$

である。



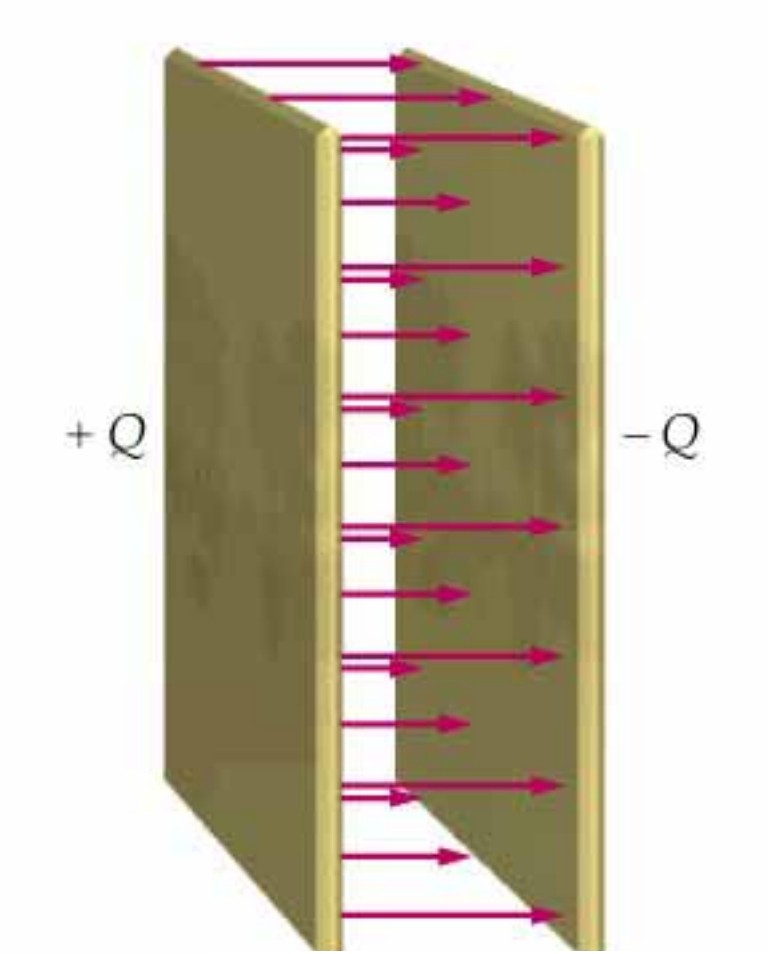
$$2\pi a^2 |\mathbf{E}| = \frac{Q}{\varepsilon}$$

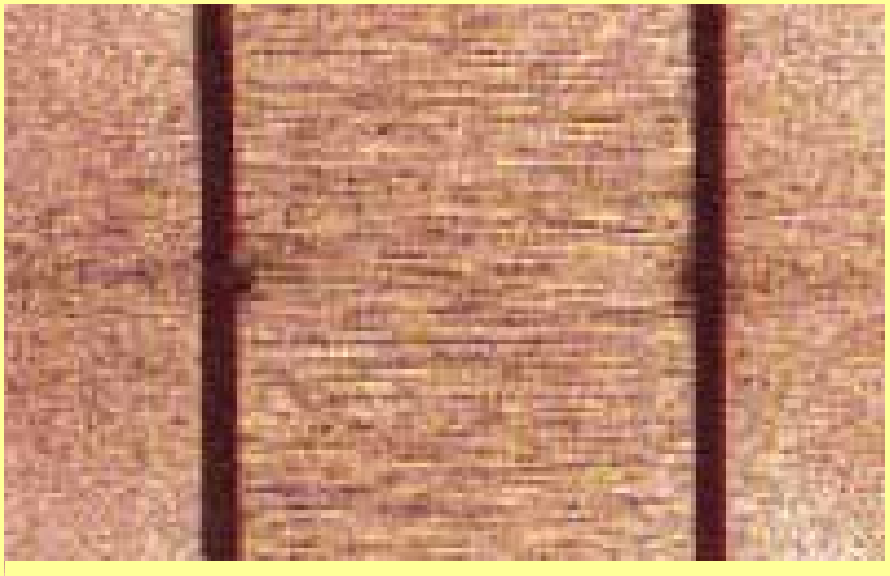
$$\sigma = \frac{Q}{\pi a^2}$$

$$E = \frac{\sigma}{2\varepsilon}$$

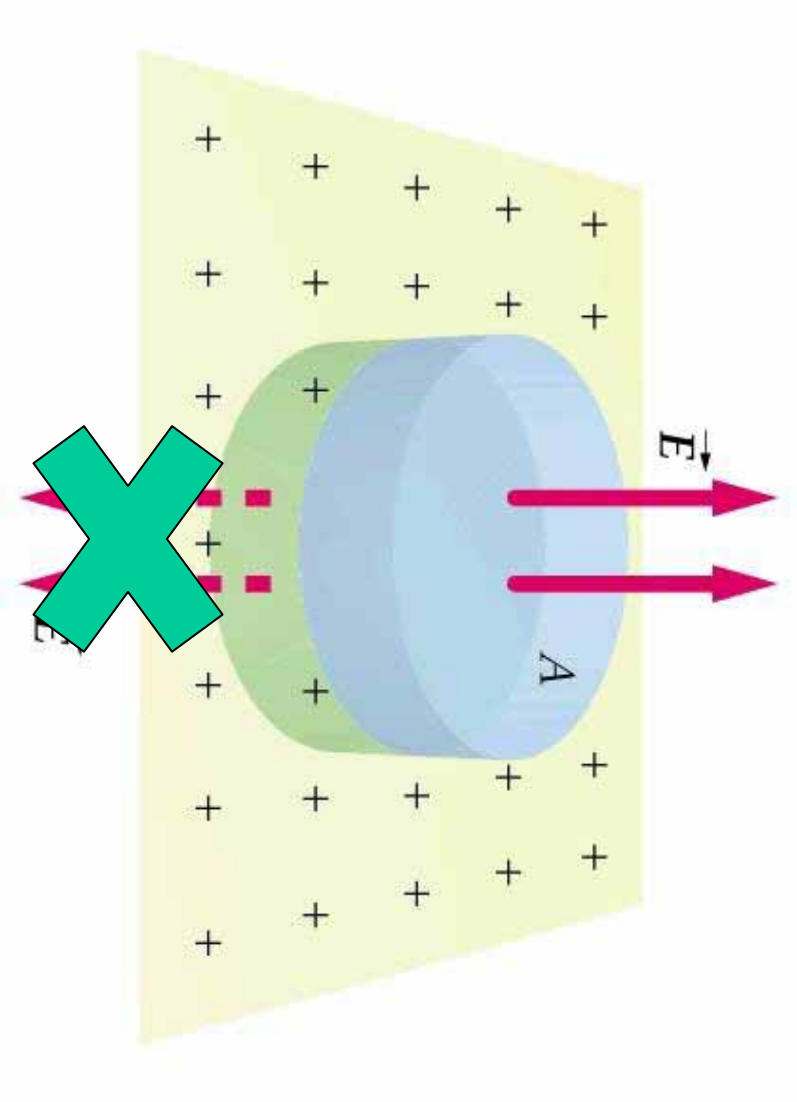
ガウスの法則まとめ

電　荷	球状	線状	平面状
閉曲面	球	円筒	箱形
電　場	$\dfrac{Q}{4\pi\varepsilon_0 r^2}$	$\dfrac{\lambda}{2\pi\varepsilon_0 r}$	$\dfrac{\sigma}{2\varepsilon}$
距離に対する変化	2乗に反比例	反比例	変化なし

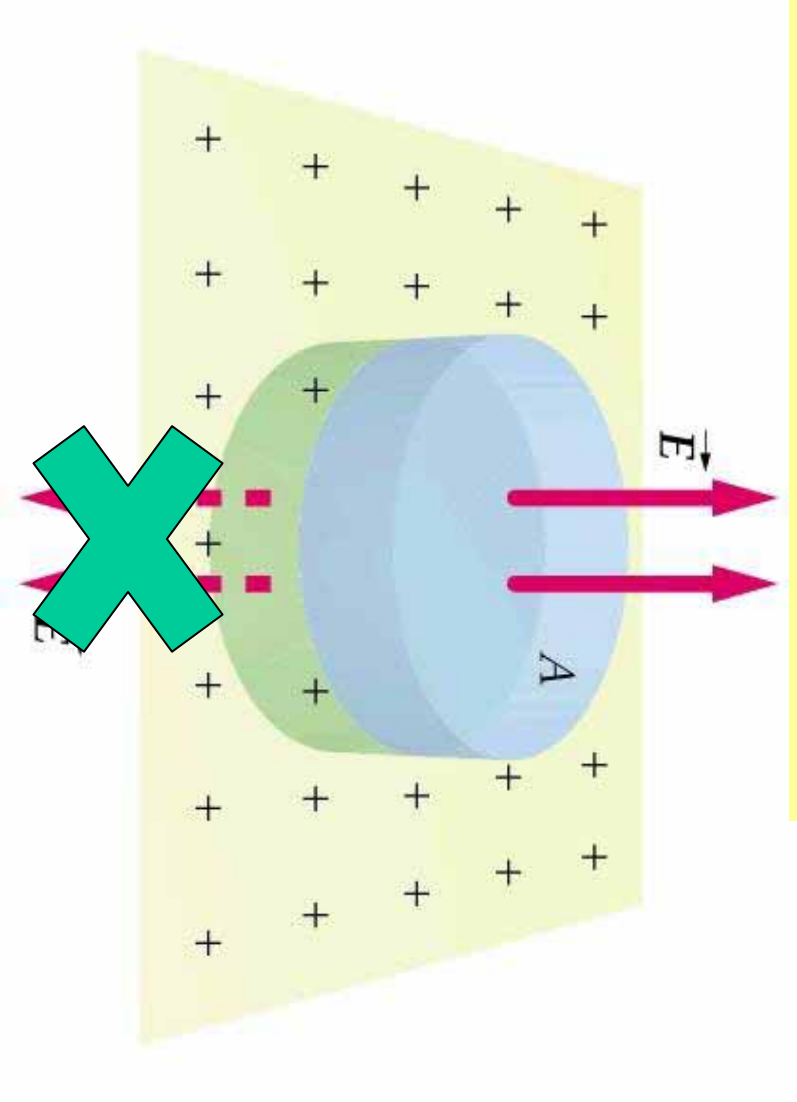




内側に電場があり
外側には電場がない

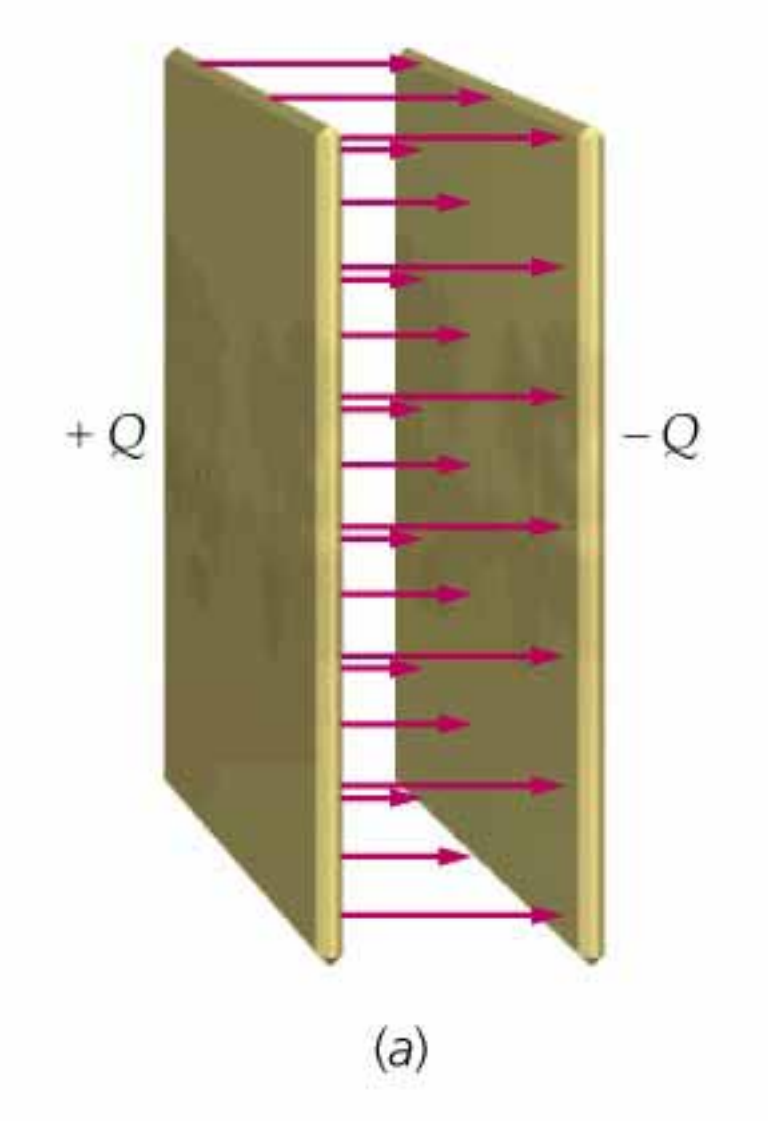


$$\pi a^2 |\boldsymbol{E}| = \frac{Q}{\varepsilon}$$



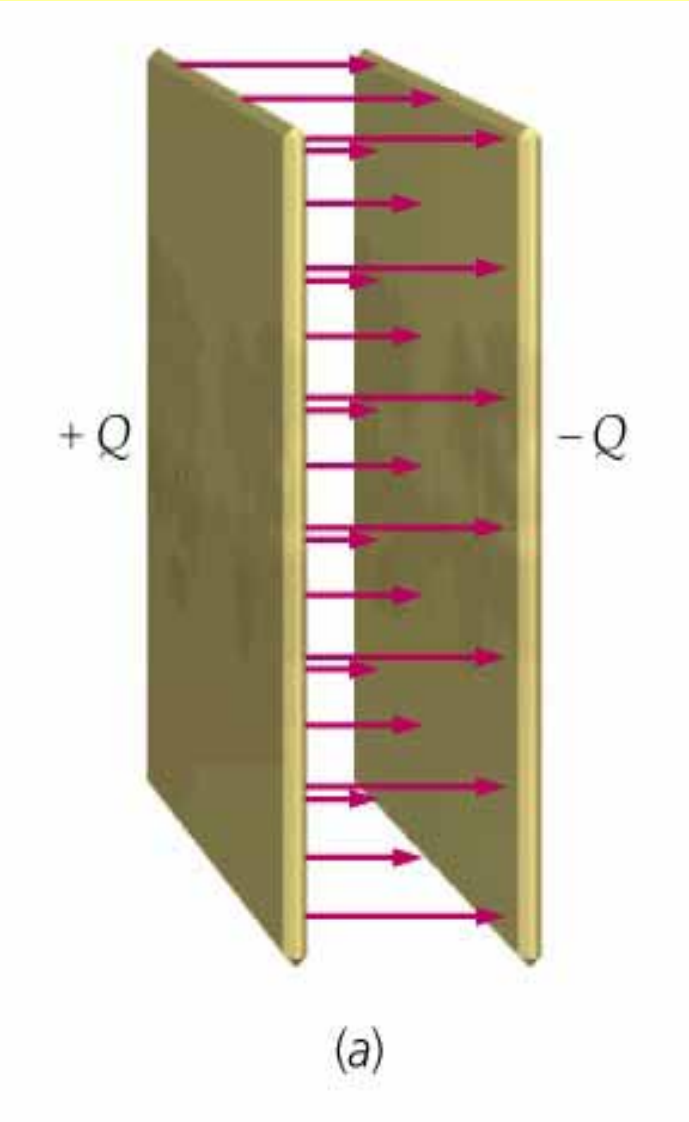
$$\pi a^2 |\boldsymbol{E}| = \frac{Q'}{\varepsilon}$$

$$\boldsymbol{E} = \frac{\text{電荷密度}}{\varepsilon}$$



$$\boldsymbol{E} = \frac{Q}{\varepsilon S}$$

$$V_0 - V_d$$

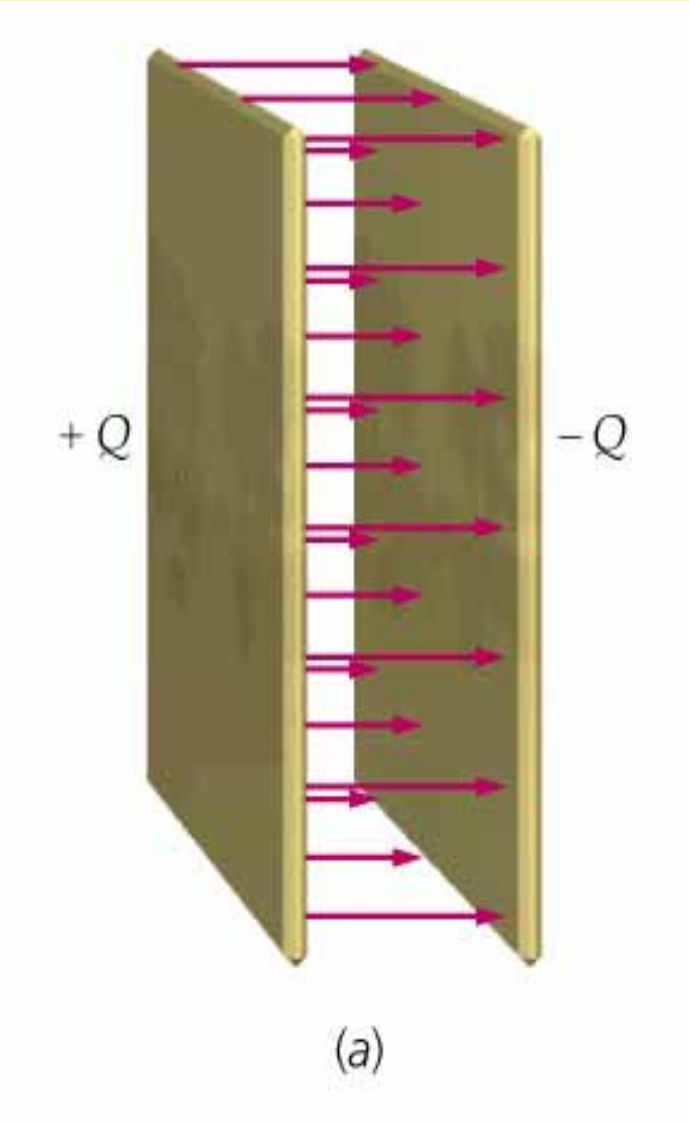


$$= -\int_0^d E \cdot dr = -\int_0^d \frac{Q}{\varepsilon S} dr$$

$$V = E \cdot d$$

電位は高校では極板の距離と電場の積と習った。

$$V_0 - V_d$$

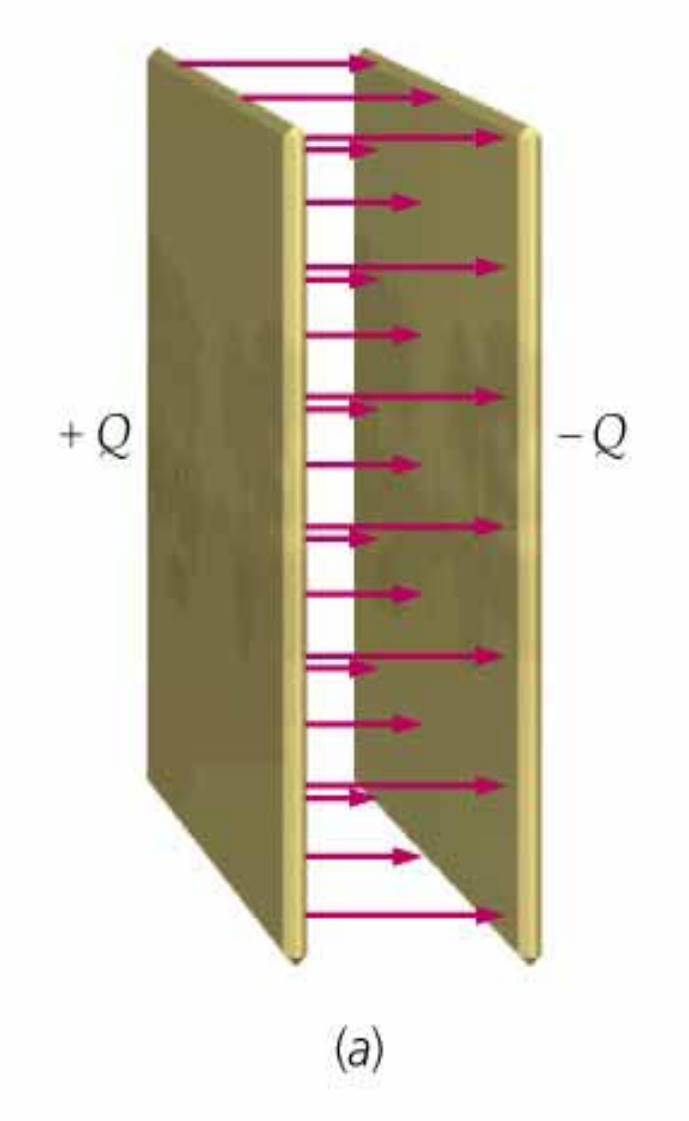


$$= -\int_0^d E \cdot dr = -\int_0^d \frac{Q}{\varepsilon S} dr$$

$$V = E \cdot d$$

電位は高校では極板の距離と電場の積と習った。

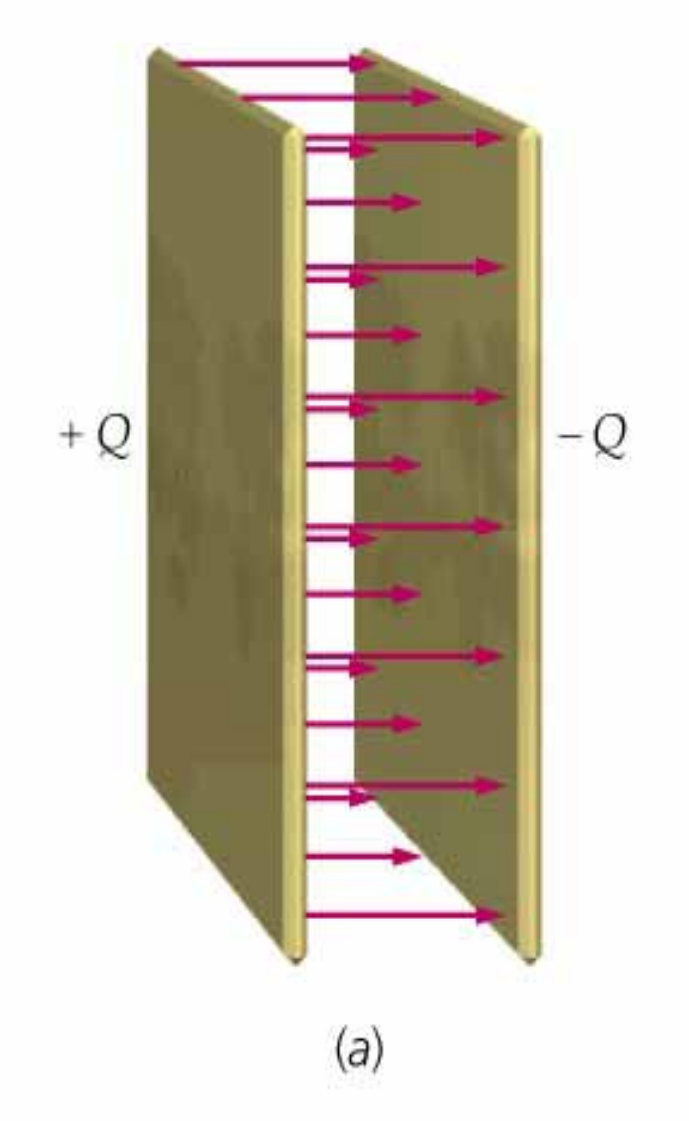
$$V = \frac{d}{\varepsilon S} \cdot Q$$



$$V = \frac{d}{\varepsilon S} \cdot Q$$

$$V = \frac{1}{C} \cdot Q$$

$$(Q = C \cdot V)$$



$$V = \frac{d}{\varepsilon S} \cdot Q$$

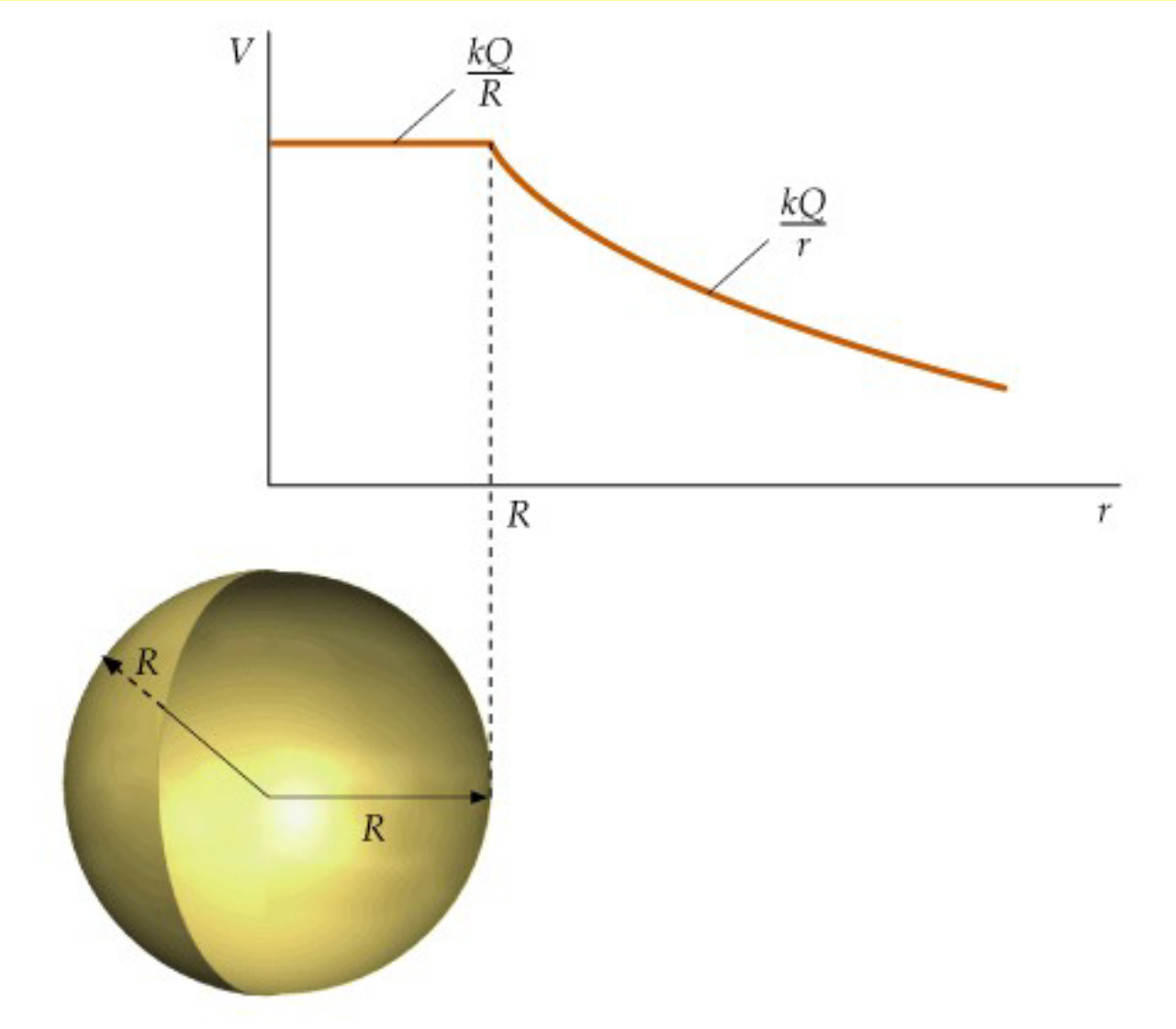
$$\left(\frac{1}{C}\right)$$

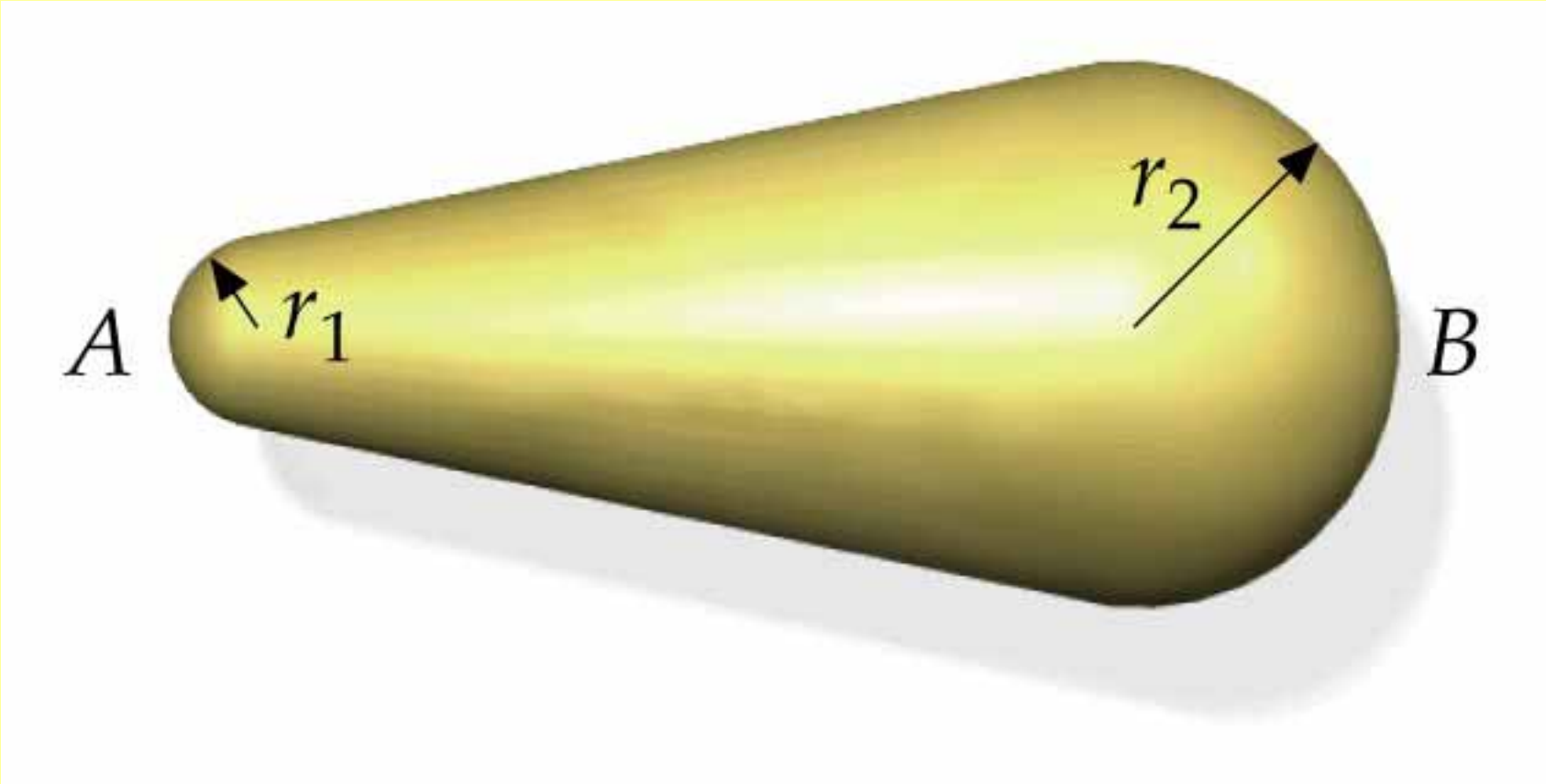
$$C = \frac{\varepsilon S}{d}$$

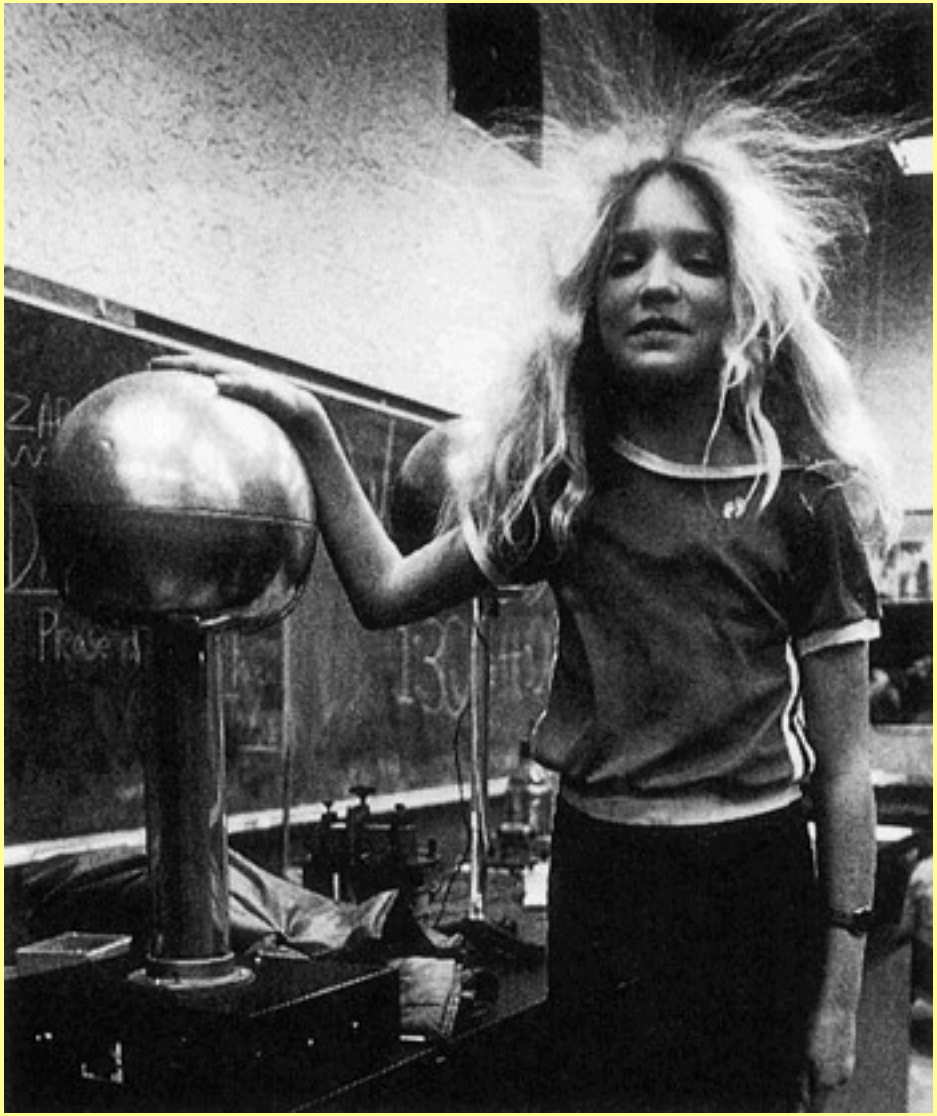
エネルギー（仕事）

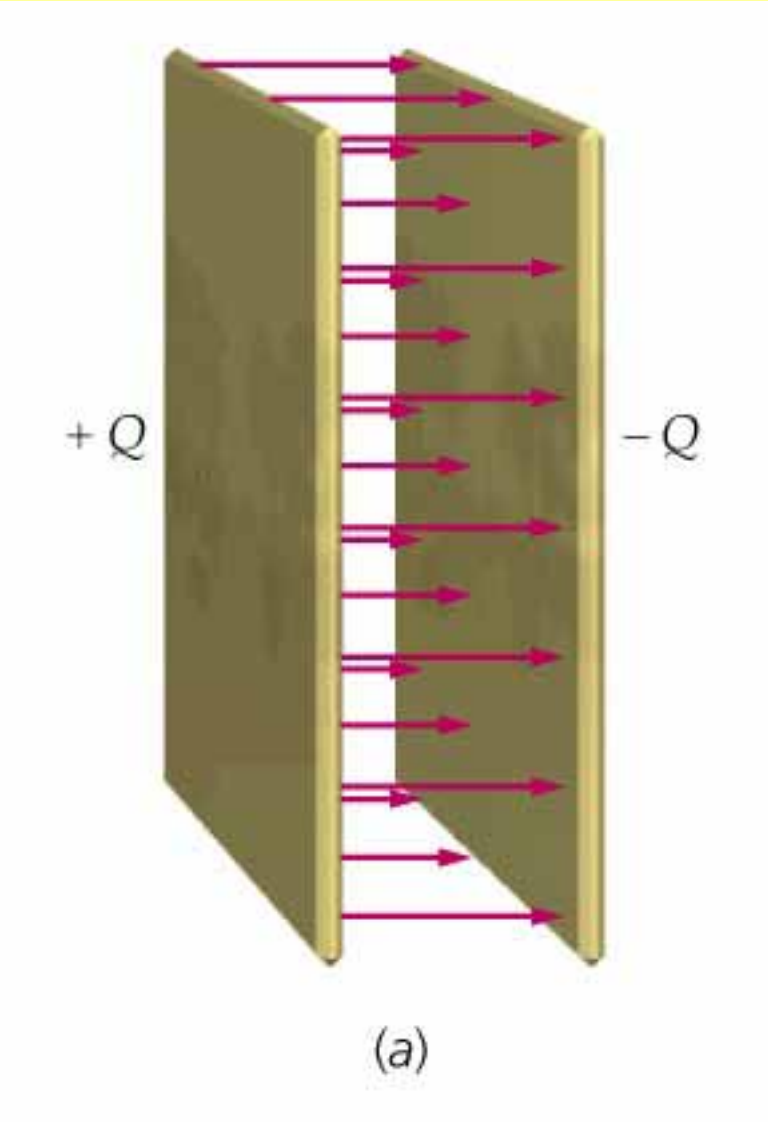
$$U = Q \cdot V$$

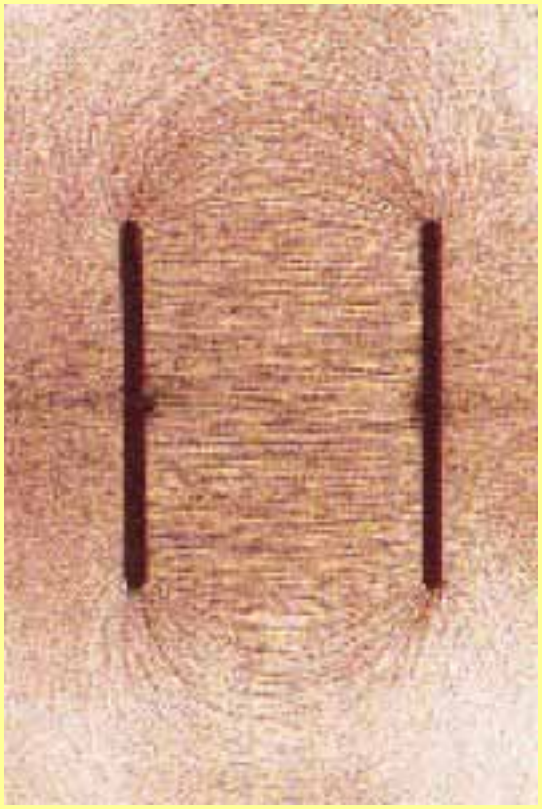
$$\boldsymbol{F} = Q \cdot \boldsymbol{E}$$

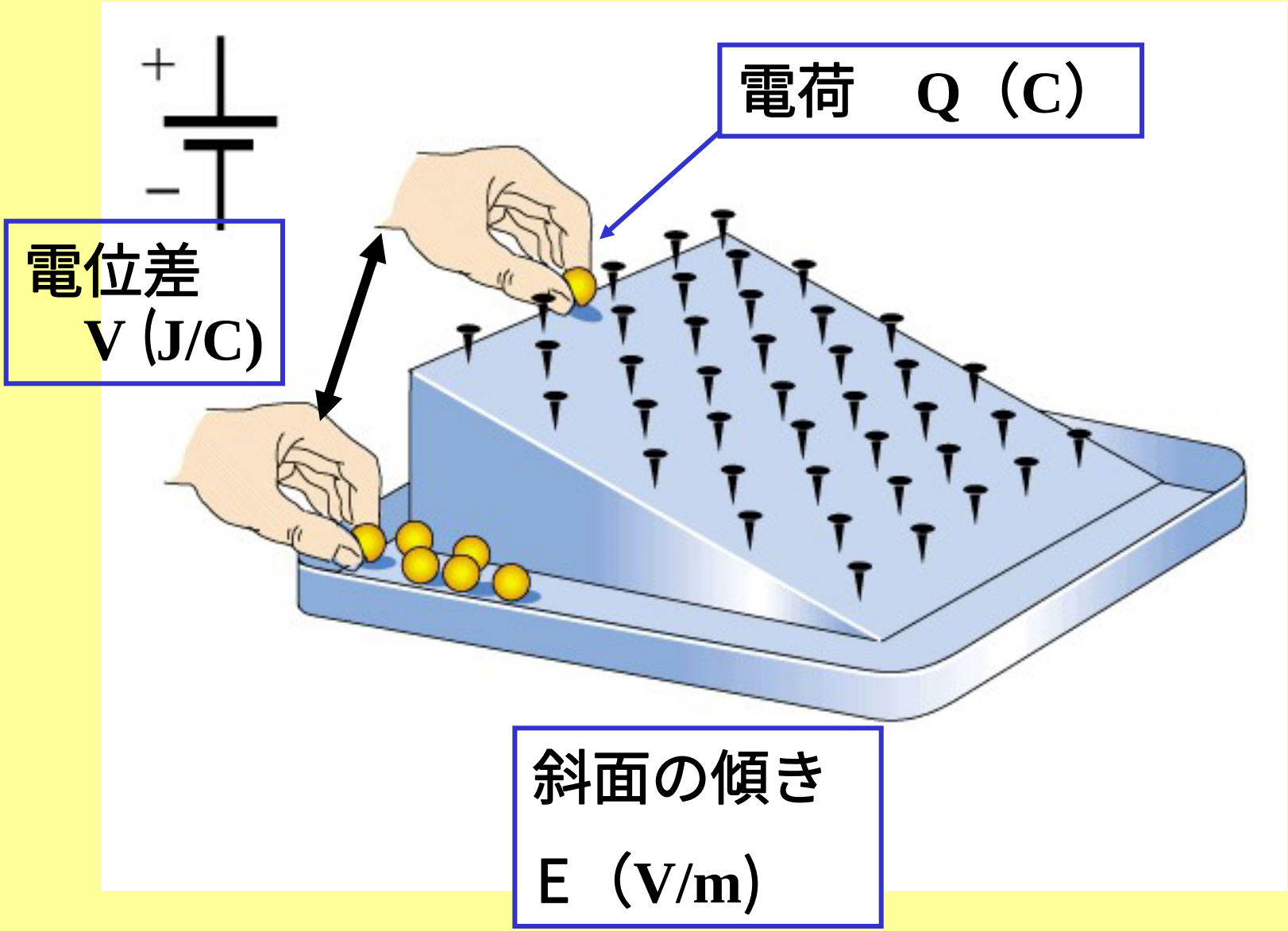

V
kQ/R
kQ/r
R
r
R
R

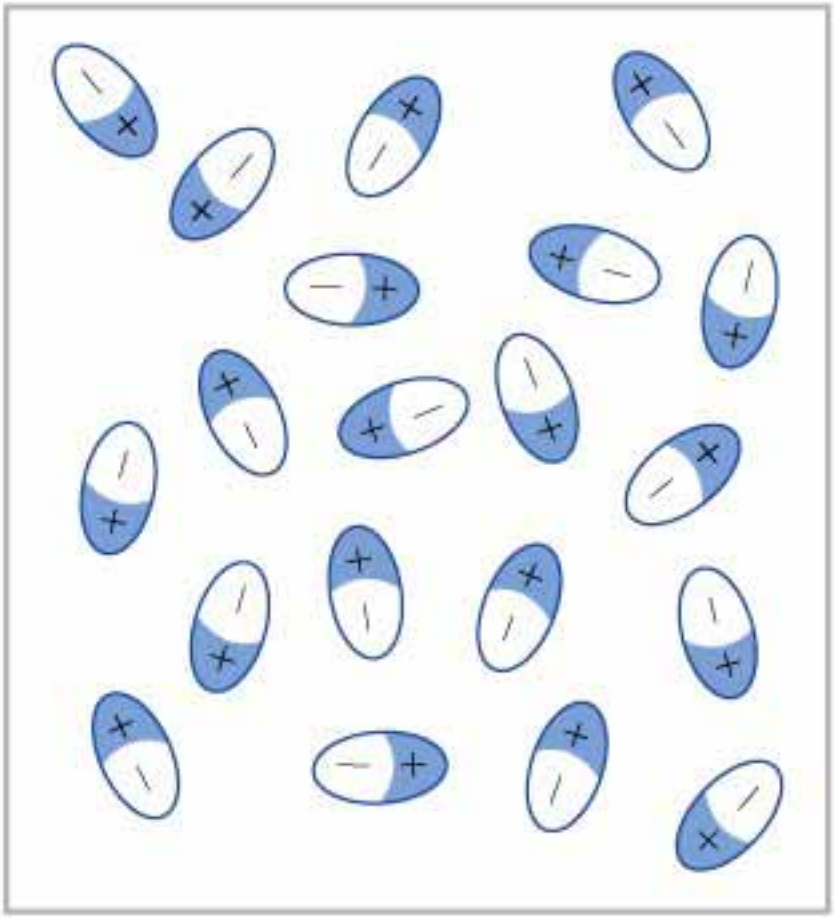

A
r_1
r_2
B



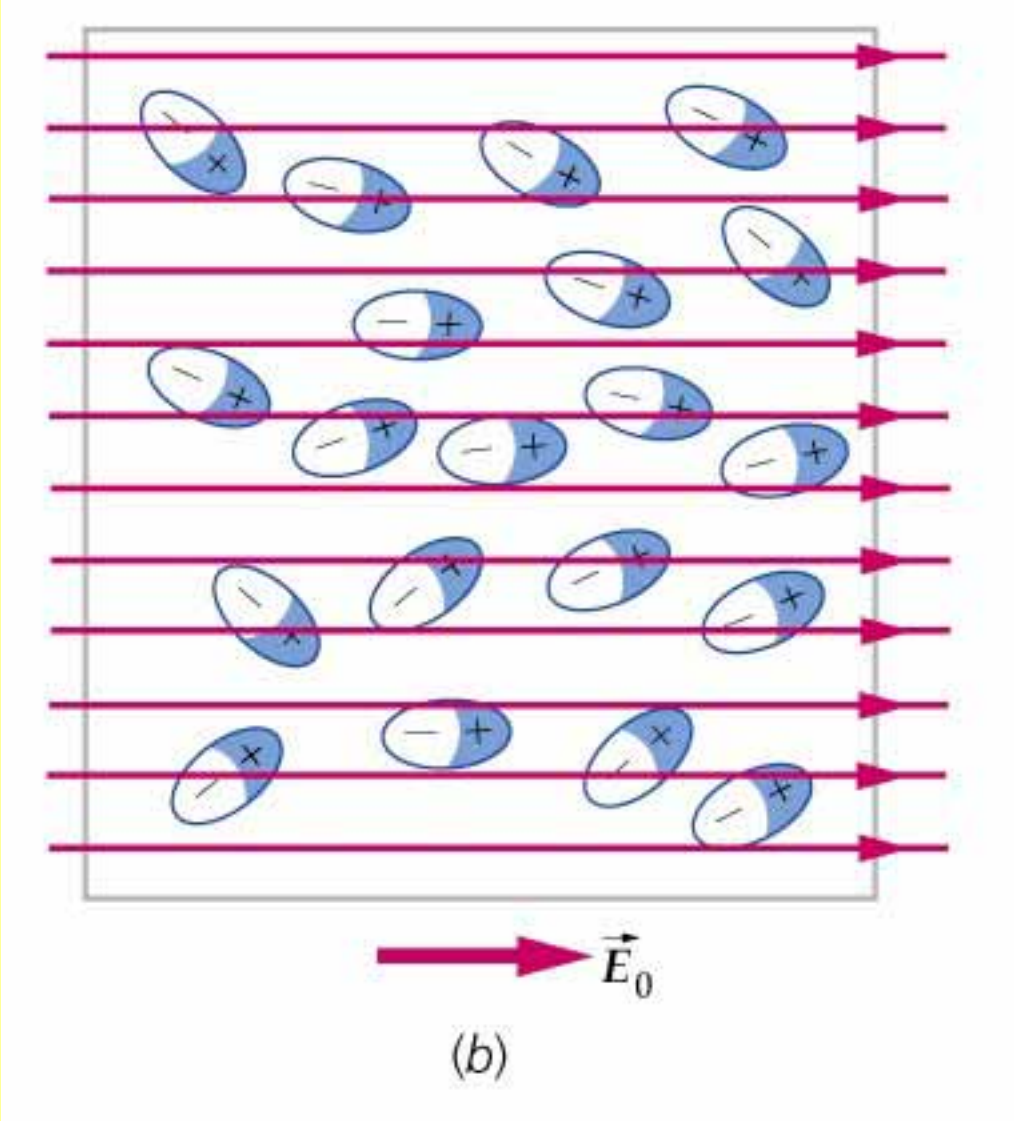

+ Q
− Q
(a)

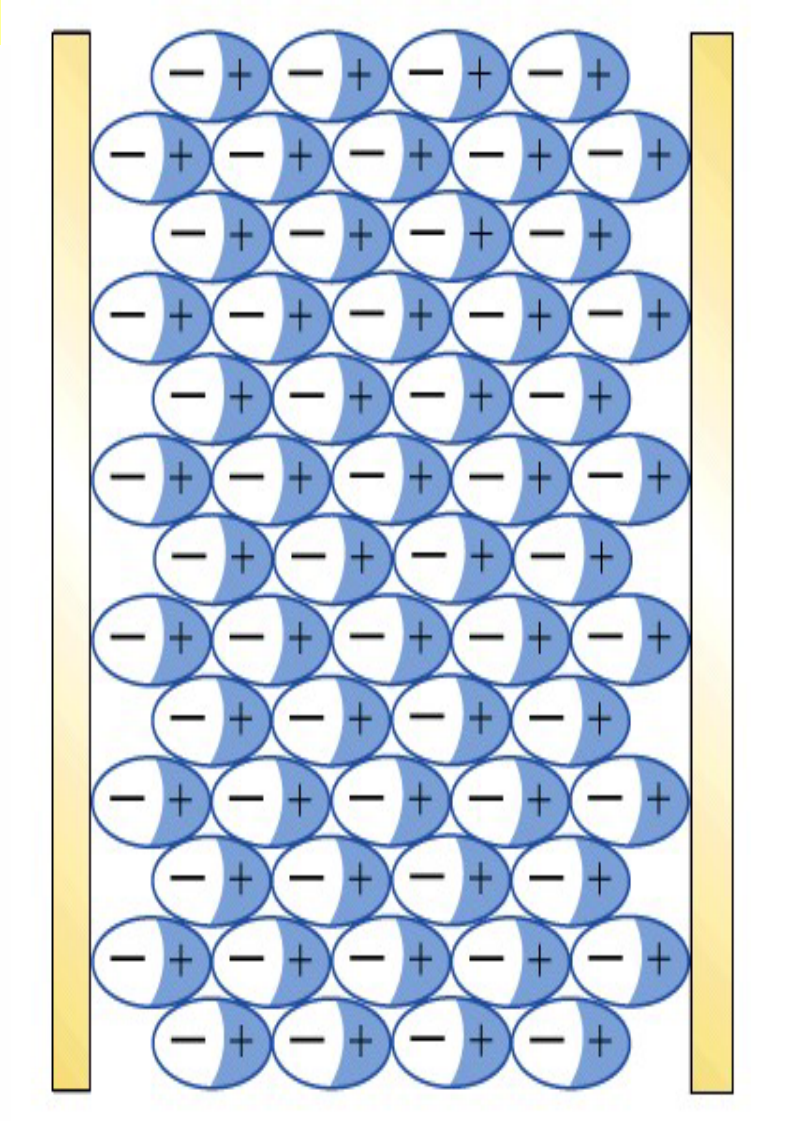


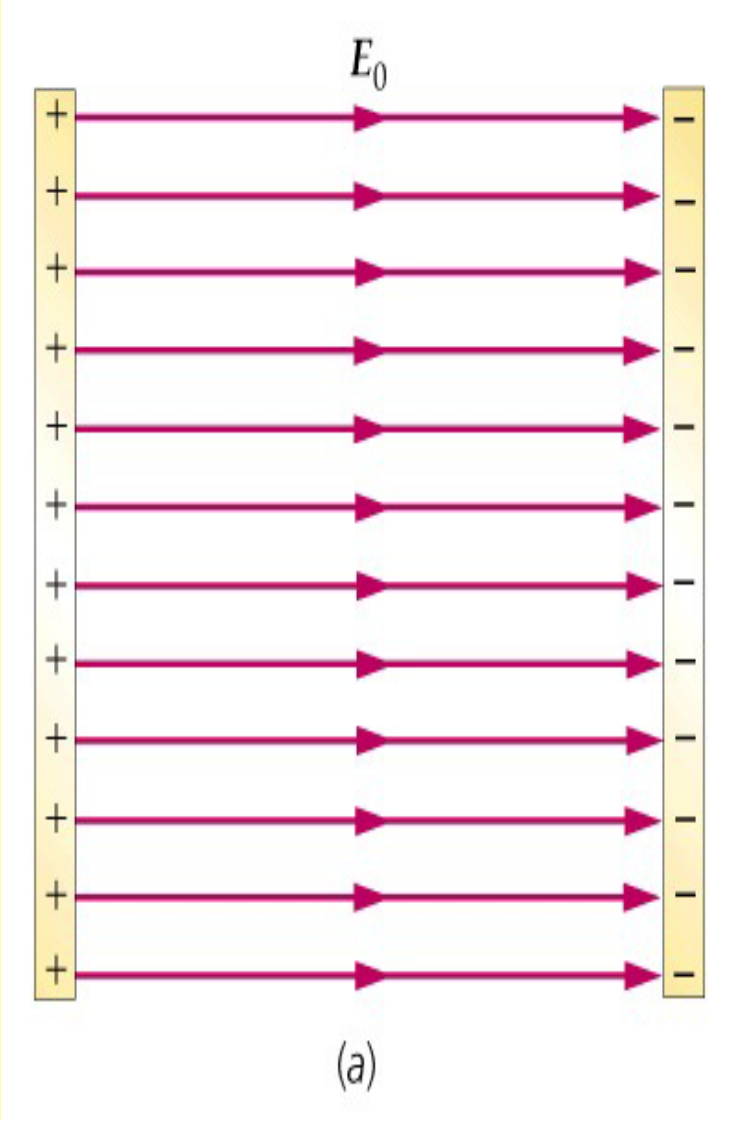

電荷　Q（C）
電位差
V (J/C)
斜面の傾き
E（V/m)

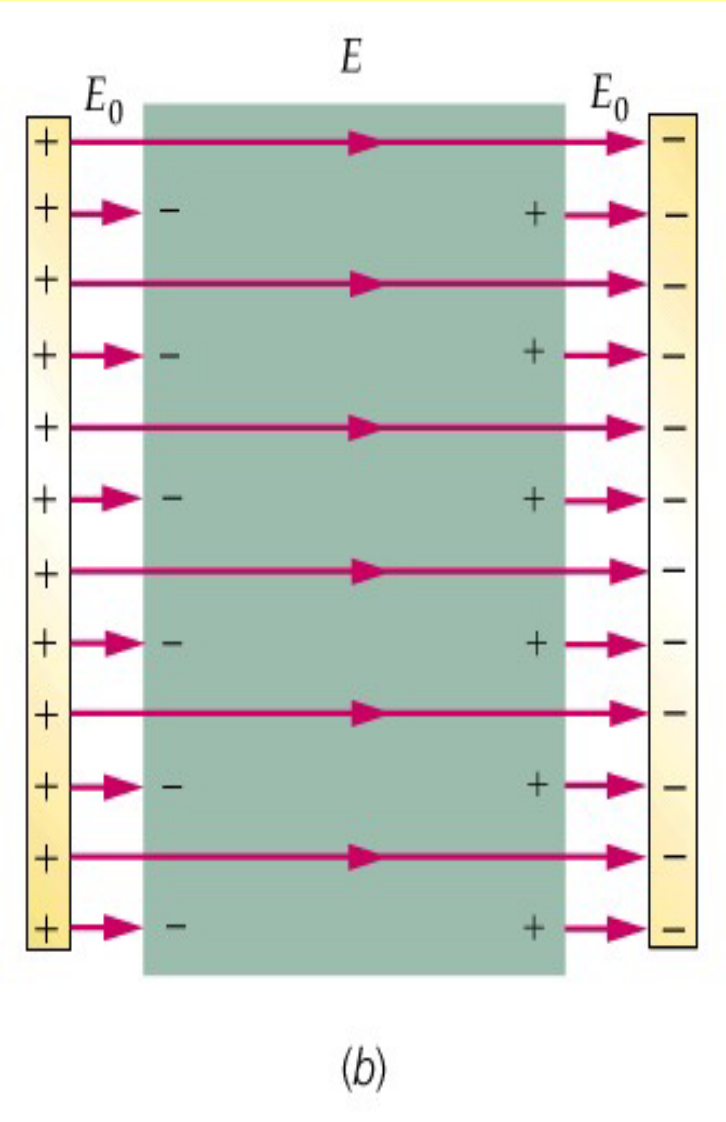


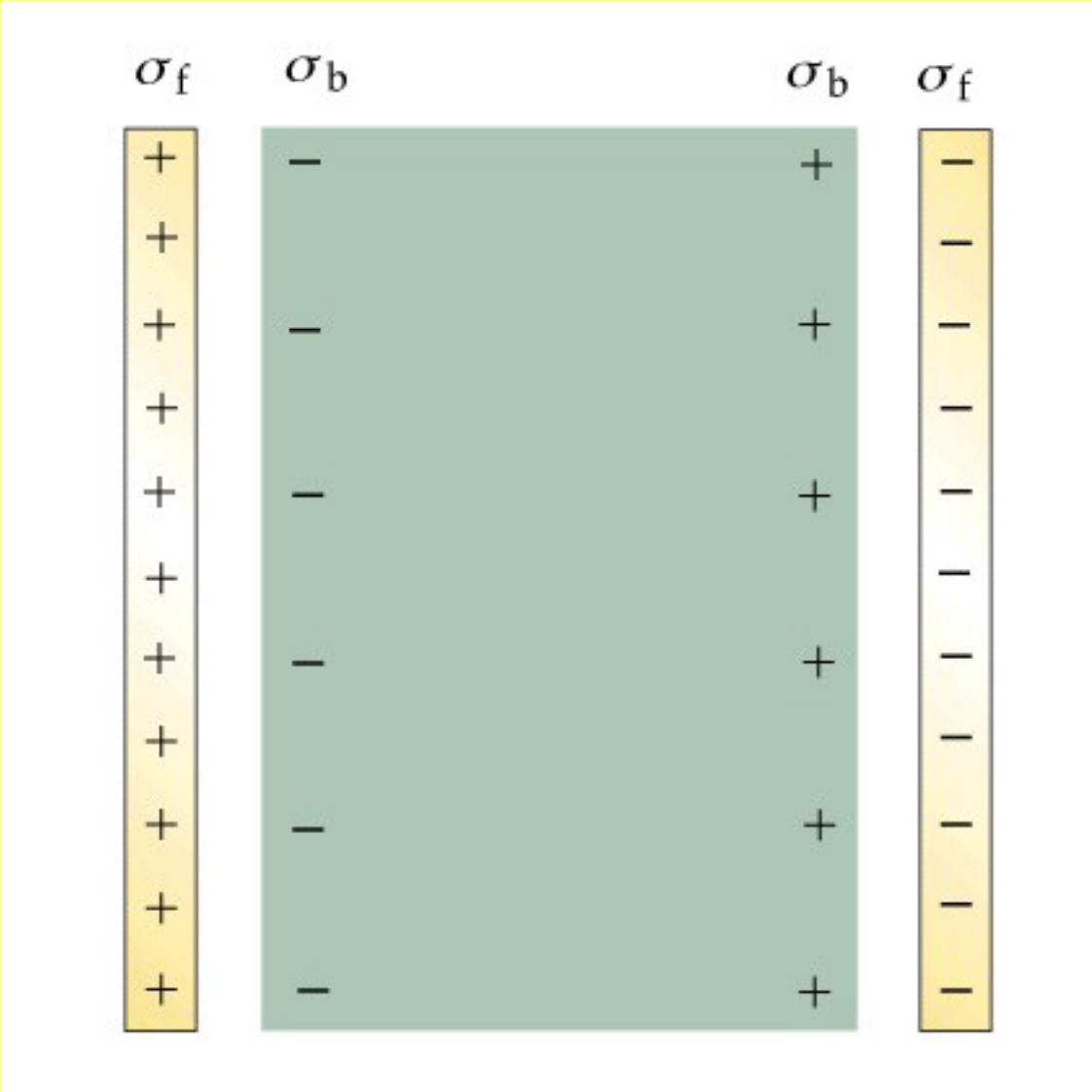
(a)

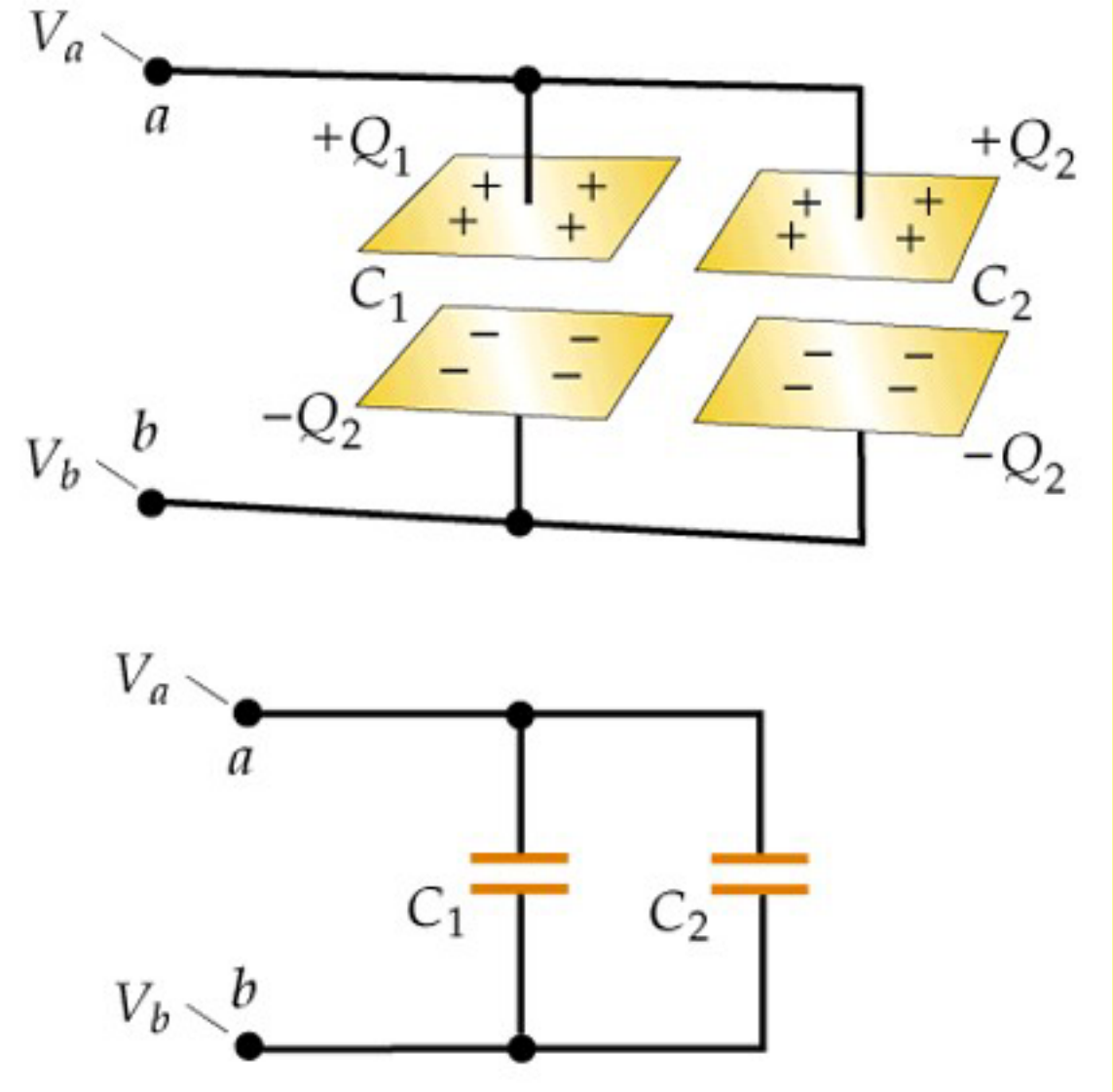

$\vec{E}_0$
(b)

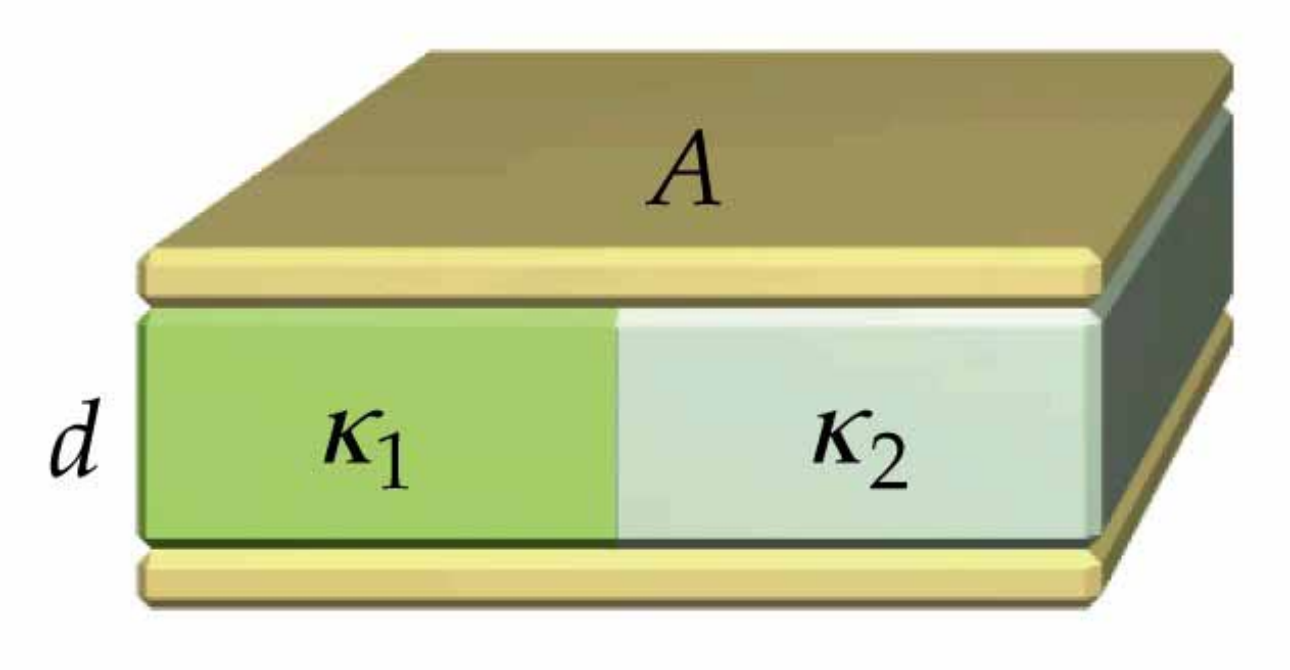


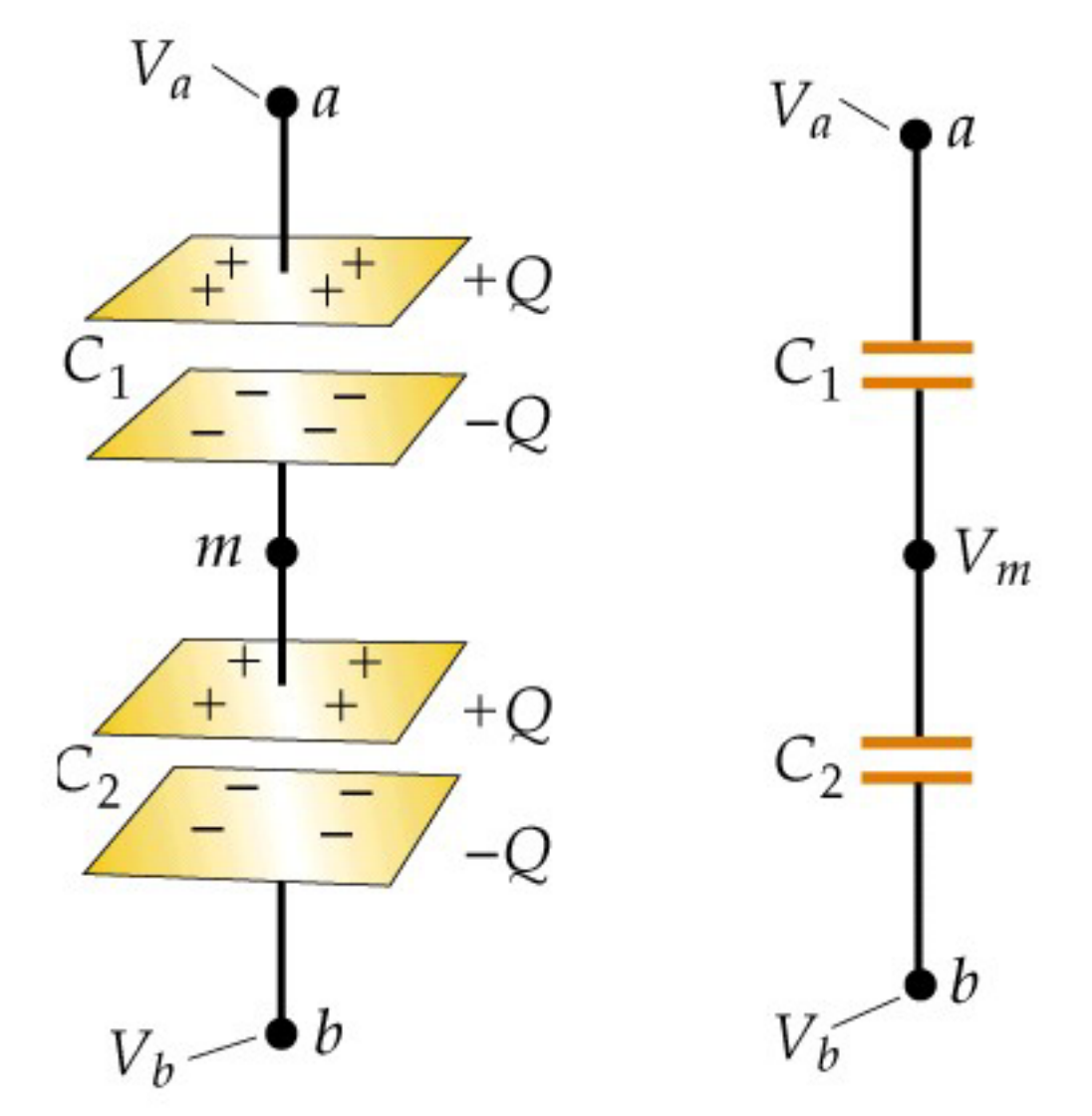

E_0
(a)

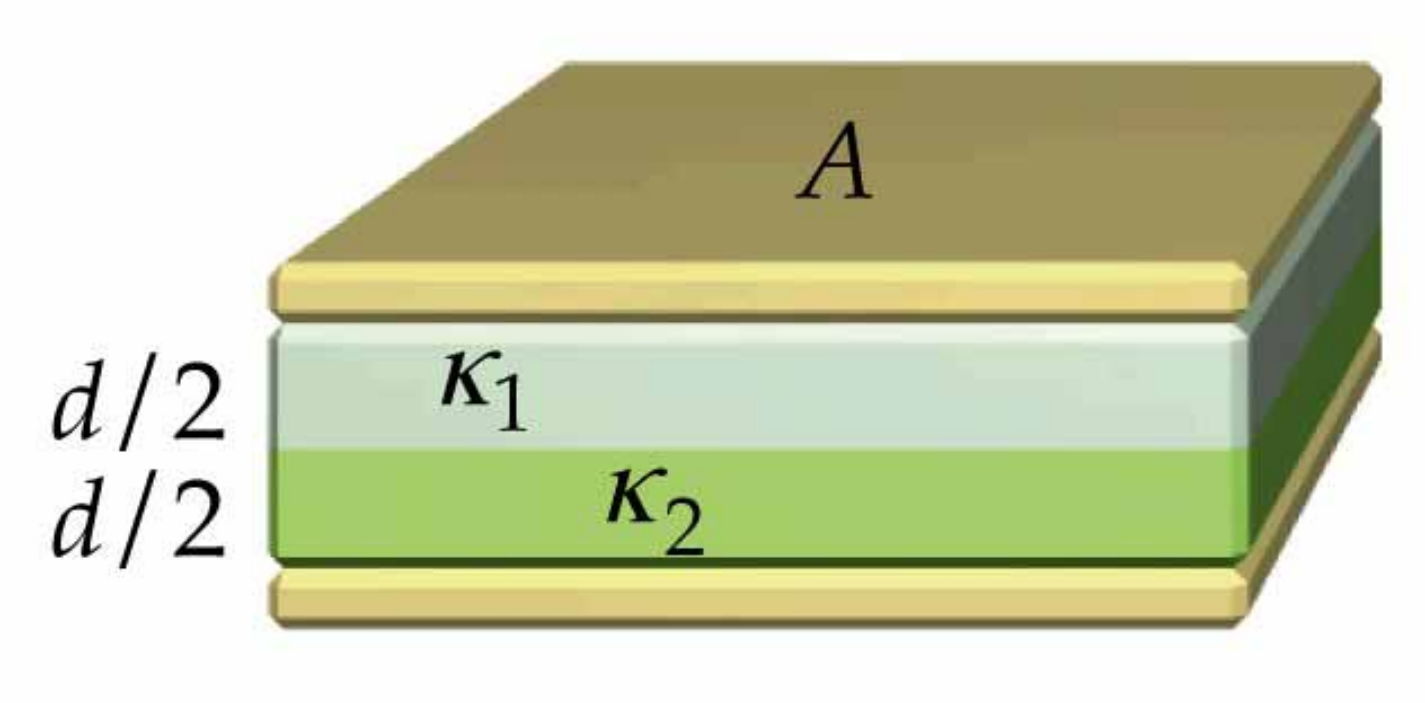

E
E_0
E_0
(b)


σ_f
σ_b
σ_b
σ_f


V_a
a
$+Q_1$
$+Q_2$
C_1
C_2
$-Q_2$
$-Q_2$
b
V_b
V_a
a
C_1
C_2
V_b
b


A
d
κ1
κ2


V_a
a
+Q
C_1
−Q
m
+Q
C_2
−Q
V_b
b
V_a
a
C_1
V_m
C_2
b
V_b


A
d/2
κ1
d/2
κ2

ガウスの法則まとめ

電　荷	球状	線状	平面状
閉曲面	球	円筒	箱形
電　場	$\dfrac{Q}{4\pi\varepsilon_0 r^2}$	$\dfrac{\lambda}{2\pi\varepsilon_0 r}$	$\dfrac{\sigma}{2\varepsilon}$
距離に対する変化	2乗に反比例	反比例	変化なし