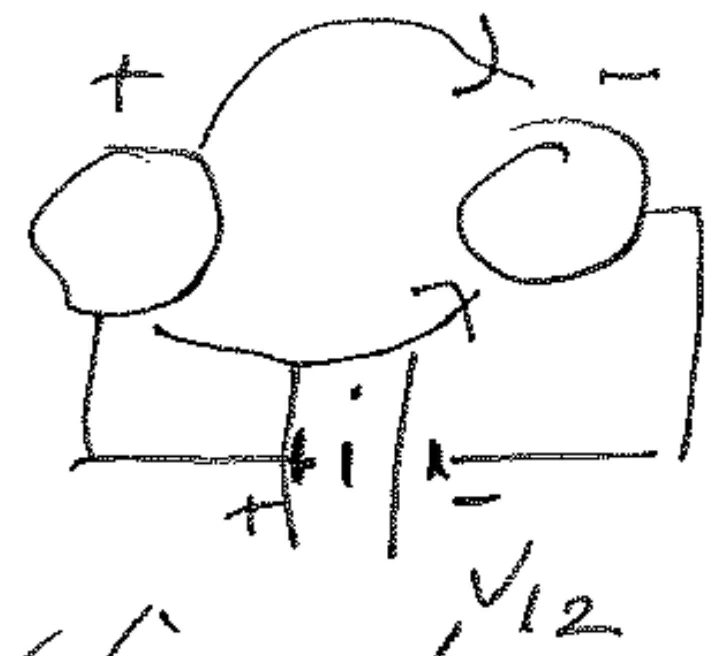
FEB 24

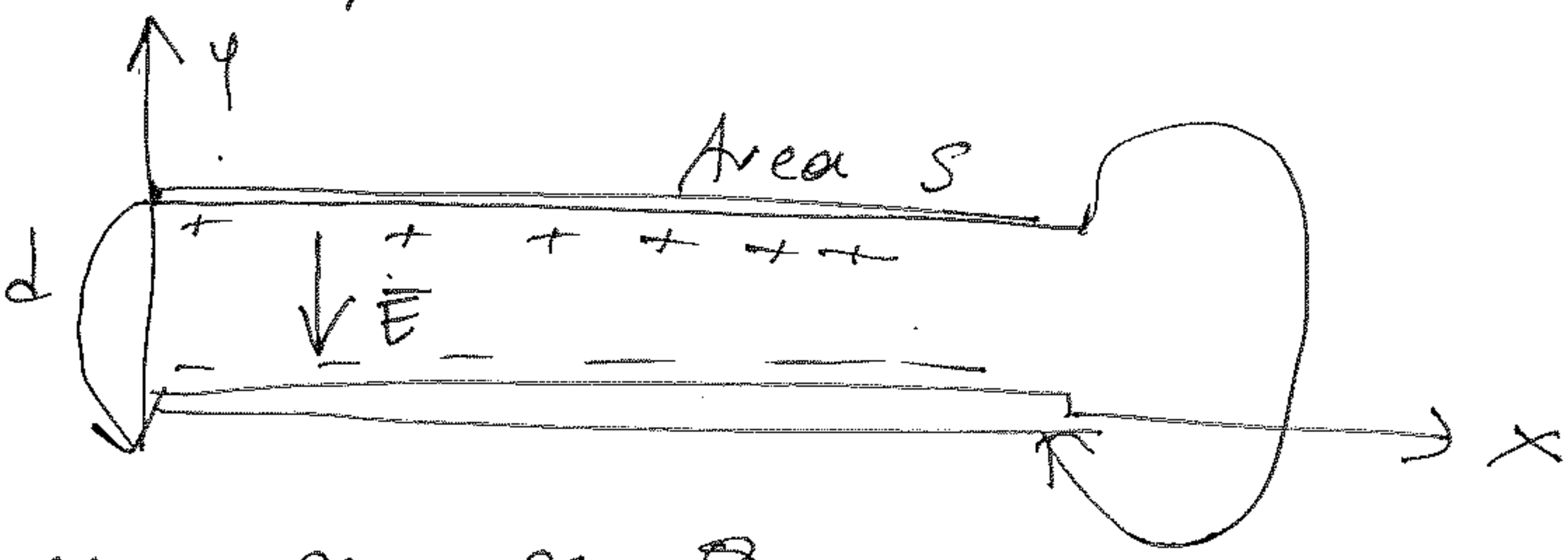
The capacitance ~~of~~ a capacitor is a physical property of the 2-conductor system; It depends on geometry and permittivity of the medium between them; A capacitor has a capacitance even when no voltage is applied



To find C :

1. Choose appropriate coordinate system
2. Assume +Q and −Q on the conductors
3. Find $\bar{E}$ from Q by
   $\boxed{E_{1n} = \frac{\rho_s}{\epsilon_1}}$ Gauss' law
4. Find V_{12} by evaluating
   $$V_{12} = -\int_2^1 \bar{E}\cdot d\bar{l}$$
   from the conductor carrying −Q to the other carrying +Q
5. Find C by taking the ratio $\frac{Q}{V_{12}}$

A parallel-plate capacitor consists of two parallel conducting plates of area S separated by a uniform distance d. The space is filled with dielectric of constant permittivity ϵ; What is the capacitance



$+\rho_s$, $-\rho_s$ $\quad \rho_s = \frac{Q}{S}$

$$\bar{E} = \frac{\rho_s}{\epsilon}(-\hat{a}_y) = -\hat{a}_y \frac{Q}{\epsilon S}$$

$$V_{12} = -\int_{y=0}^{y=d} \bar{E} \cdot d\bar{l} = -\int_0^d (-\hat{a}_y)\frac{Q}{\epsilon S} \cdot (\hat{a}_y \, dy)$$

$$= \frac{Q}{\epsilon S} d$$

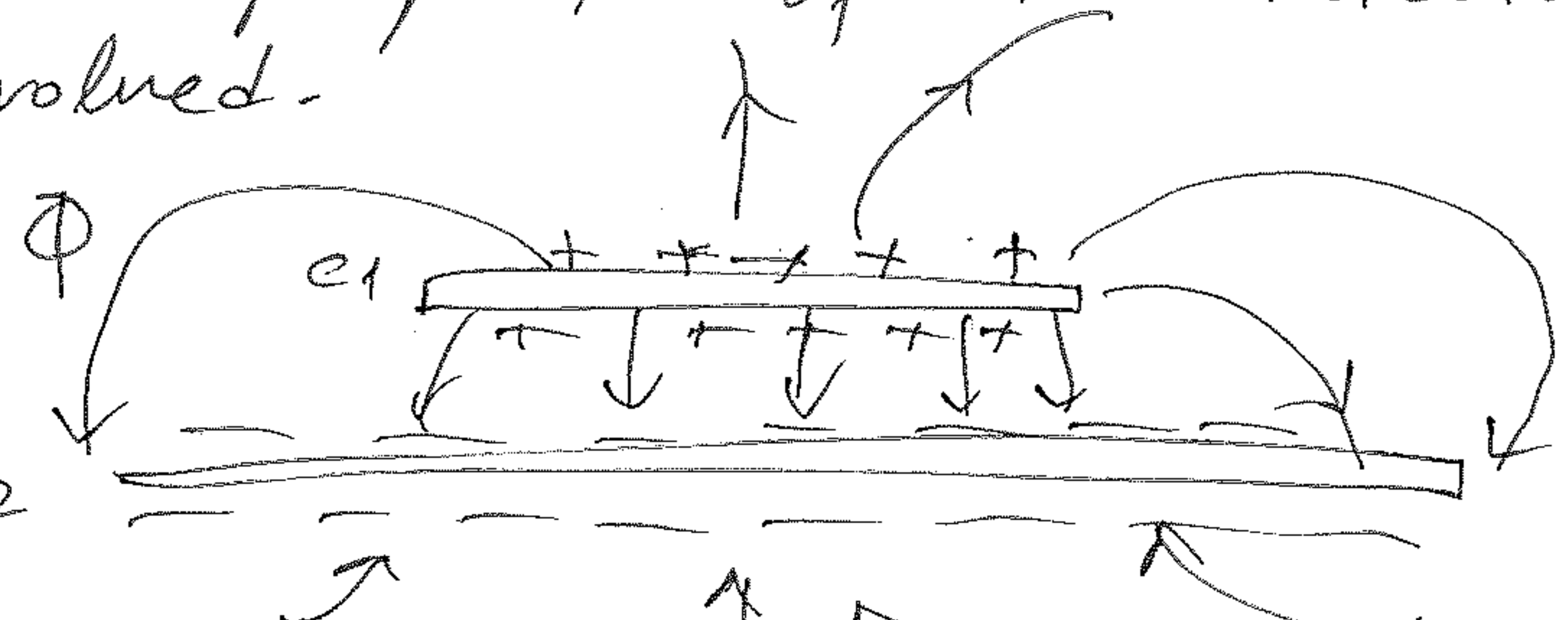
$$C = \frac{Q}{V_{12}} = \epsilon \frac{S}{d}$$

CAPACITANCE

Any two conducting bodies separated by free space or a dielectric material have a capacitance between them
A voltage difference applied results in a charge +Q on one conductor and −Q on the other. The ratio of the absolute value of the charge to the absolute value of the voltage difference is defined as the capacitance of the system:

$$C = \frac{Q}{V} \ (F) \qquad 1F = 1\frac{C}{V}$$

The capacitance depends only on the geometry of the system and the properties of the dielectrics involved.



+Q is placed on C1 (conductor 1) and −Q on C2

the flux of the electric field is as shown

Parallel plate capacitor

$$C = \frac{Q}{V_{12}} = \epsilon \frac{S}{d}$$

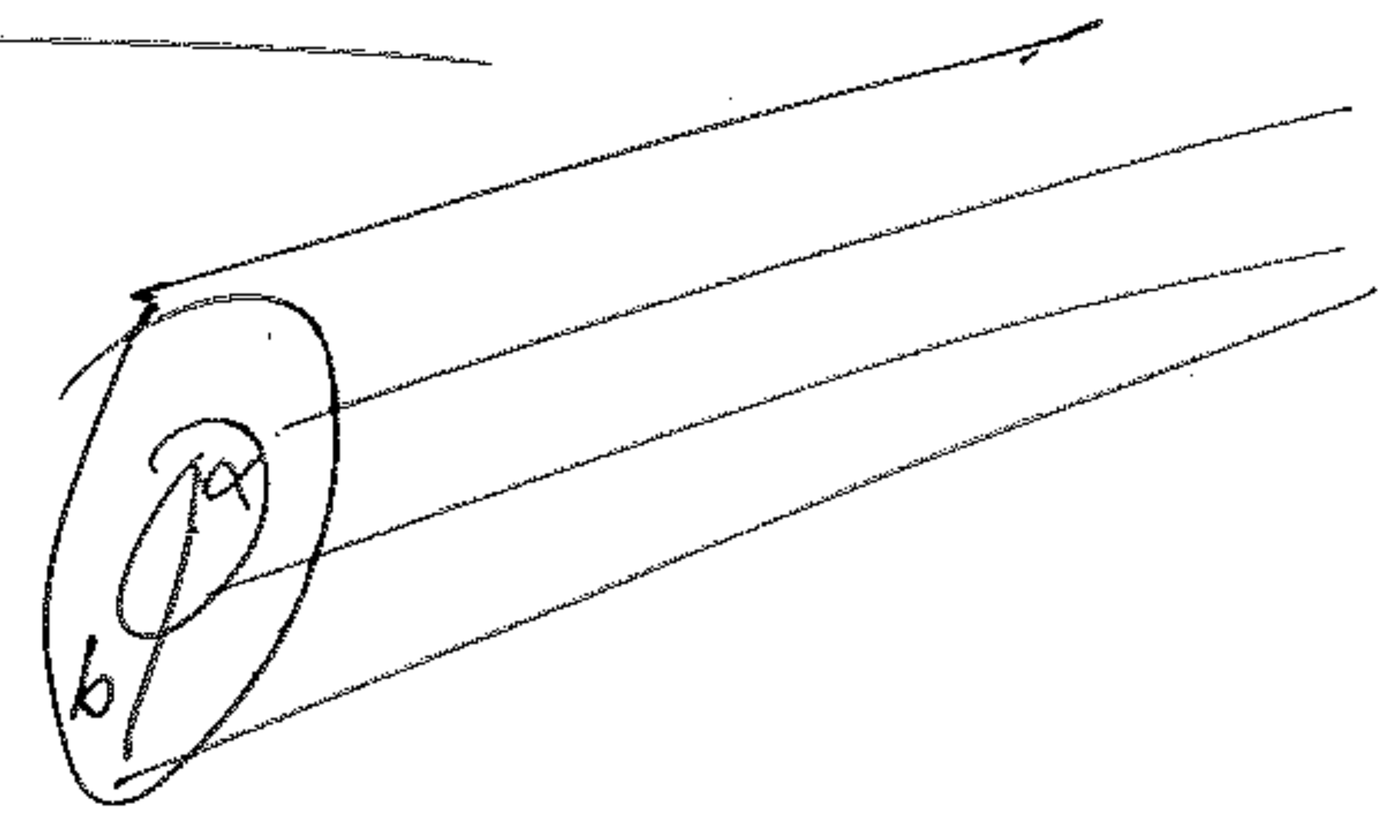
independent of Q or V_{12}

2) Cylintrical capacitor

A cylintrical capacitor consist of inner conductor of radius a and outer of radius b. The space is filled with dielectric of permitivity ϵ and the lenght of the capacitor is L.

Capacitance?

→ Use cylintrical



assume charges $+Q, -Q$ on the surface of the inner conductor and the inner surface of the outer conductor

derive $\bar{E}$ (gauss law in $a < r < b$.

$$\bar{E} = \hat{a}_r E_r = \hat{a}_r \frac{Q}{2\pi \epsilon L r}$$

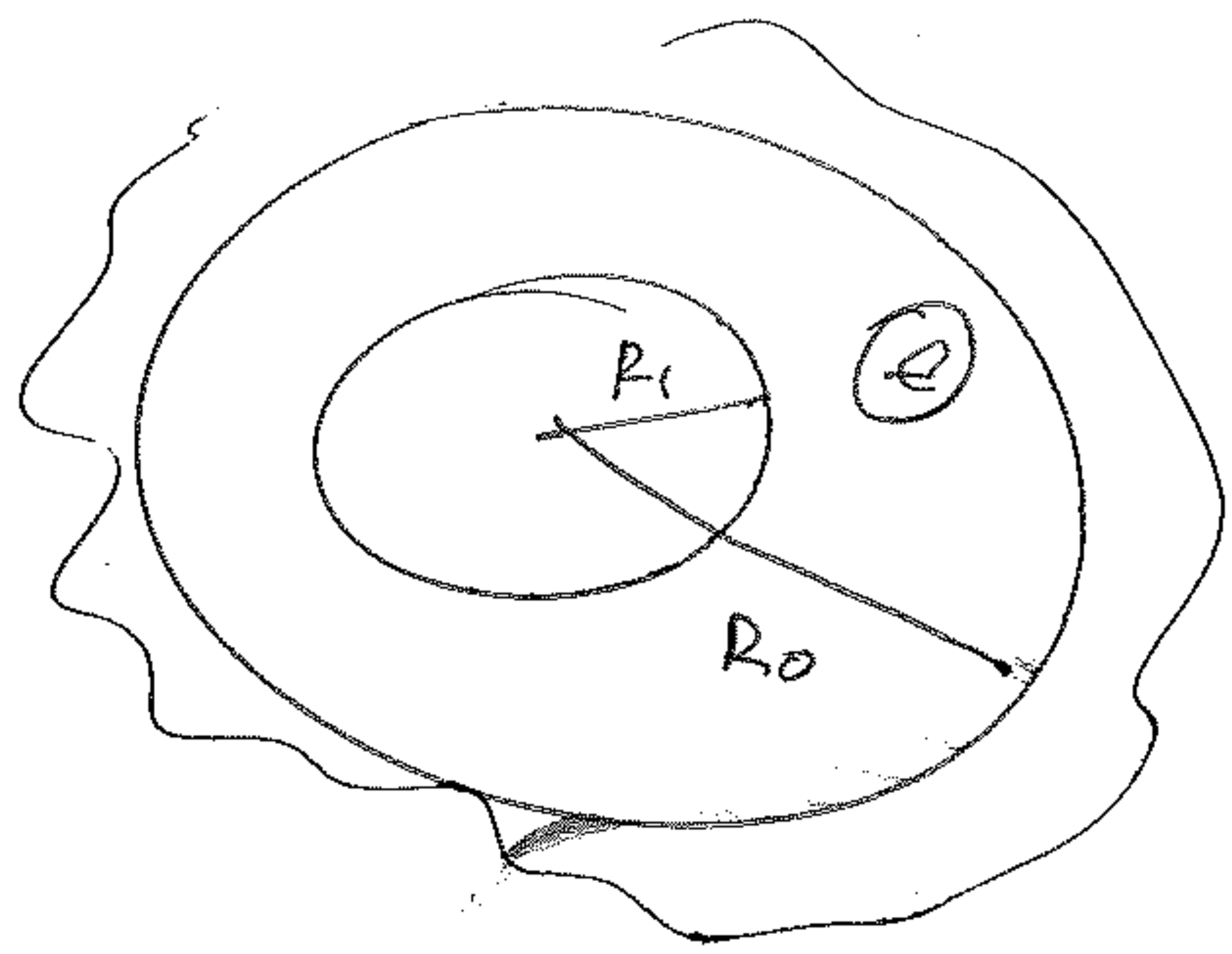
$$V_{ab} = -\int_{r=b}^{r=a} \bar{E} \cdot d\bar{l} = -\int_{b}^{a} \left(\hat{a}_r \frac{Q}{2\pi\epsilon L r}\right) \cdot (\hat{a}_r \, dr)$$

$$= \frac{Q}{2\pi\epsilon L} \ln \frac{b}{a}$$

Cylinthical capacitor

$$C = \frac{Q}{V_{ab}} = \frac{2\pi\epsilon L}{\ln \frac{b}{a}}$$

A spherical capacitor consists of an inner conducting sphere of radius R_i and an outer conductor with a spherical inner wall of radius R_o. Space in between permitivity ϵ. What is he capacitance?



assume $+Q$, $-Q$ on he inner and outer conductors of he spherical capacitor. Gauss' law R $(R_i < R < R_o)$ we have

$$\bar{E} = \hat{a}_R E_R = \hat{a}_R \frac{Q}{4\pi\epsilon R^2}$$

$$V = -\int_{R_o}^{R_i} \bar{E} \cdot (\hat{a}_R \, dR) =$$

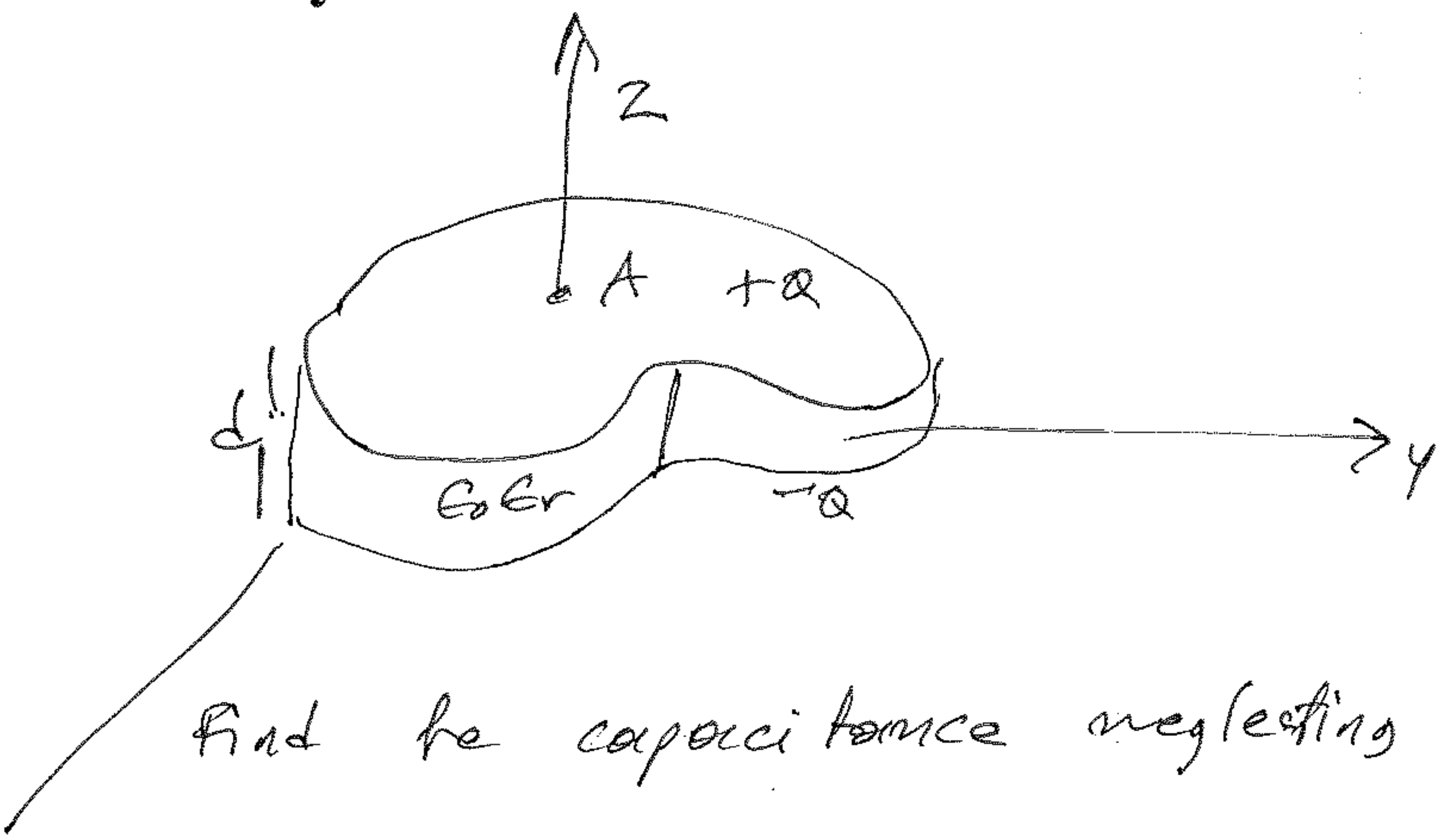
$$= -\int_{R_o}^{R_i} \frac{Q}{4\pi\epsilon R^2} \, dR = \frac{Q}{4\pi\epsilon}\left(\frac{1}{R_i} - \frac{1}{R_o}\right)$$

Shprerical capacitor $C = \frac{Q}{V} = \frac{4\pi\epsilon}{\frac{1}{R_i} - \frac{1}{R_o}}$

Flux → 1 above $\bar{E}$ and $\bar{D}$

To ~~to~~ double the charges would simply double $\bar{E}$ and $\bar{D}$ ~~that~~ ⇒ double the V ⇒ $C = Q/V$

$(V = -\int \bar{E} \cdot d\bar{l})$



Find the capacitance neglecting fringing

with +Q on top and −Q on the bottom

$$\rho_s = \frac{Q}{A} \qquad \boxed{E_\perp = \frac{\rho_s}{\epsilon_0}}$$

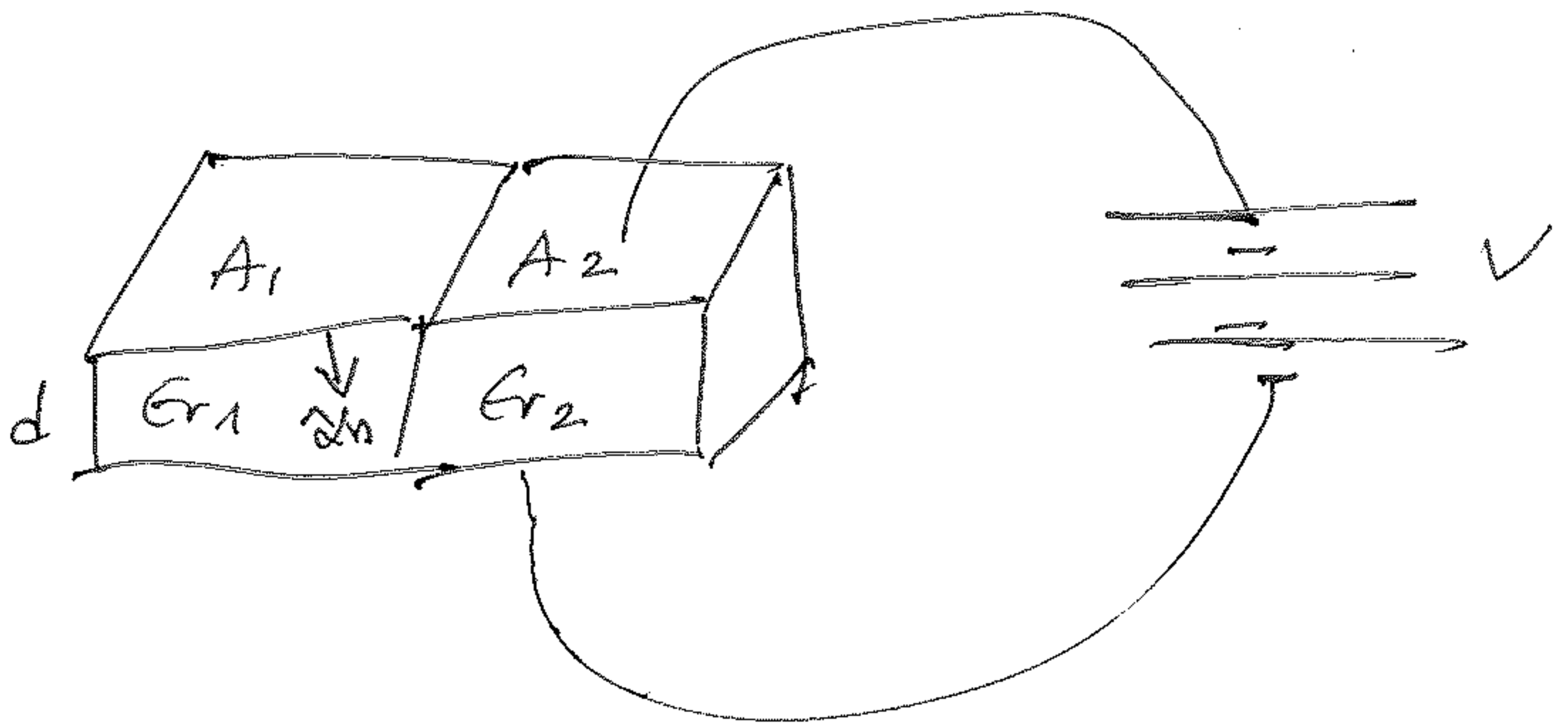
$$D_n = \rho_s = \frac{Q}{A}$$

$$\bar{D} = \frac{Q}{A}(-\hat{a}_z) \qquad \bar{E} \Rightarrow \frac{Q}{A\epsilon_0\epsilon_r}(-\hat{a}_z)$$

$$= \epsilon_0 \epsilon_r \bar{E}$$

$$V = -\int_0^d \frac{Q}{\epsilon_0 \epsilon_r A}(-\hat{a}_z) \cdot dz\,\hat{a}_z =$$

$$= \frac{Qd}{\epsilon_0 \epsilon_r A} \qquad \boxed{C = \frac{Q}{V} = \frac{\epsilon_0 \epsilon_r A}{d}}$$



show that $C_{eq} = \frac{\epsilon_0 \epsilon_{r1} A_1}{d} + \frac{\epsilon_0 \epsilon_{r2} A_2}{d} = C_1 + C_2$

Side-by-side dielectrics: "the equivalent capacitance is the sum of the individual capacitances"

V is common

$$\bar{E}_1 = \bar{E}_2 = \frac{V}{d}\hat{a}_n$$

$$\cancel{\frac{D_n}{\frac{\epsilon_0 \epsilon_{r2} A}{d_2}}}$$

$$\bar{D} = \epsilon_0 \epsilon_r \bar{E} \Rightarrow \bar{E} = \frac{\bar{D}}{\epsilon_0 \epsilon_r}$$

$$\frac{\bar{D}_1}{\epsilon_0 \epsilon_{r1}} = \frac{\bar{D}_2}{\epsilon_0 \epsilon_{r2}} = \frac{V}{d}\hat{a}_n$$

$\hat{a}_n$: is the downward normal to the upper plate

$$D_n = \rho_s$$

$$\rho_{s1} = \frac{V}{d}\epsilon_0 \epsilon_{r1}$$

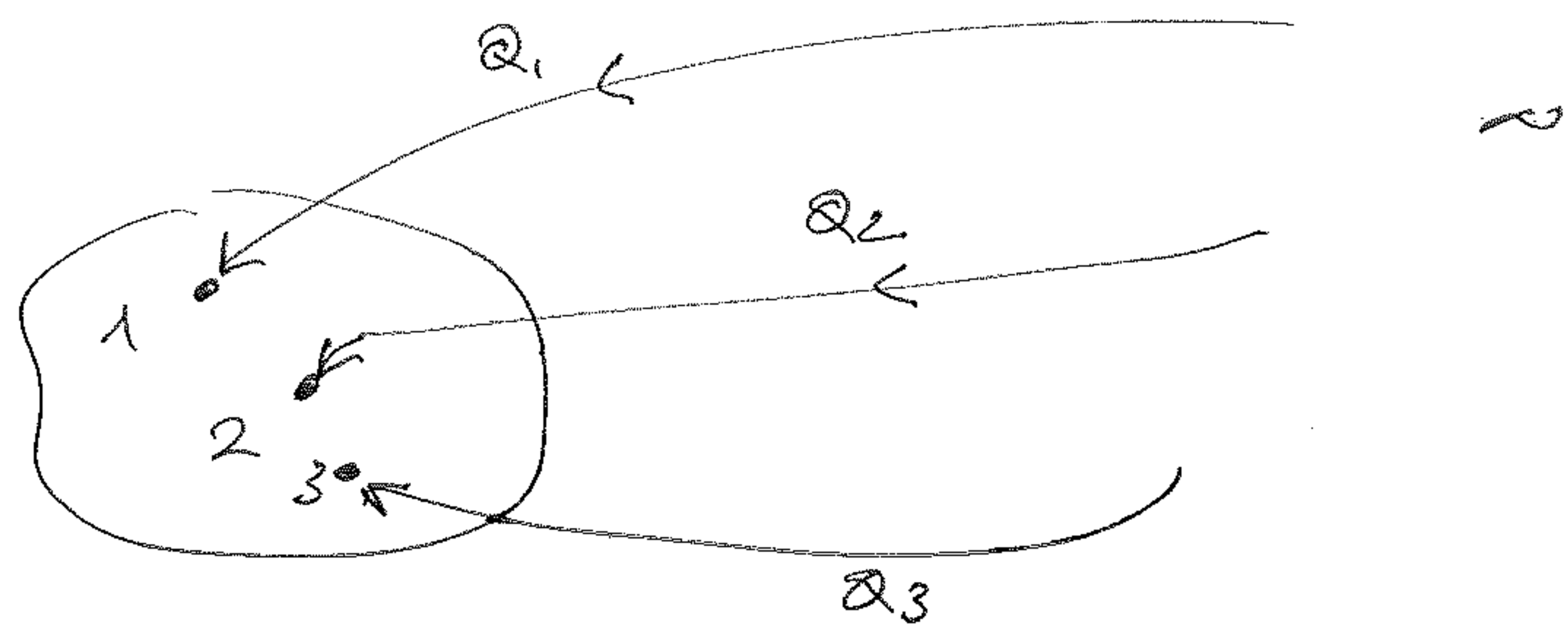
$\cancel{\rho_s}$ $\boxed{E_1 = \frac{\rho_s}{\epsilon_0} = \frac{V}{d}}$

$$\rho_{s2} = \frac{V}{d}\epsilon_0 \epsilon_{r2}$$

$$Q = \rho_{s1} \cdot A_1 + \rho_{s2} \cdot A_2 = V\left(\frac{\epsilon_0 \epsilon_{r1} A_1}{d} + \frac{\epsilon_0 \epsilon_{r2} A_2}{d}\right)$$

$$C_{eq} = \frac{Q}{V} = C_1 + C_2$$

Energy in static E field



Consider the work done to assemble charge by charge a distribution $n=3$ point charges. The region is assumed initially to be charge free and with $\bar{E}=0$ throughout

to bring $Q_1 \longrightarrow 1$ $\quad W_1 = 0$ (no $\bar{E}$)

to bring $Q_2 \longrightarrow 2$ $\quad W_2 = Q_2 \cdot V_{2,1}$

the potential @ point 2 due to charge 1

to bring $Q_3 \rightarrow 3$ $\quad W_3 = Q_3 V_{3,1} + Q_3 V_{3,2}$

$$\overline{W_E} = 0 + W_2 + W_3 = 0 + Q_2 V_{2,1} + Q_3 V_{3,1} + Q_3 V_{3,2}$$

If the charges were put in reverse order

$$\underline{W_E} = \underset{\substack{\parallel \\ 0}}{W_3} + \underset{\substack{\parallel \\ W_2}}{Q_2 V_{3,2}} + Q_1 V_{1,3} + Q_1 V_{1,2}$$

$$2W_E = \underbrace{Q_1 (V_{1,2} + V_{1,3})}_{Q_1 \cdot V_1} + Q_2 (\underbrace{V_{2,1} + V_{2,3}}_{V_2}) + Q_3 (\underbrace{V_{3,1} + V_{3,2}}_{V_3})$$

V_1 is the potential @ P1 $\qquad 2W_E = Q_1 V_1 + Q_2 V_2 + Q_3 V_3$

$$W_E = \frac{1}{2}\left(Q_1 V_1 + Q_2 V_2 + Q_3 V_3\right) = \frac{1}{2}\sum_{m=1}^{n} Q_m V_m$$

for a region containing n point charges

For a region w/ charge density ρ (C/m³)
the summation becomes integration

$$W_E = \frac{1}{2}\int \rho V dv$$

other forms

$$W_E = \frac{1}{2}\int \bar{D}\cdot\bar{E}\, dv$$

$$W_E = \frac{1}{2}\int \epsilon E^2 dv$$

$$W_e = \frac{1}{2}\int \frac{D^2}{\varepsilon} dv$$

same

In an electric circuit the energy stored in the field of a capacitor is given by

$$W_E = \frac{1}{2} Q V^2 = \frac{1}{2} C V^2$$

where C is the capacitance in Farads and V is the voltage difference between 2 conductors making up the capacitor an Q is the magnitude of total charge in one of the conductors

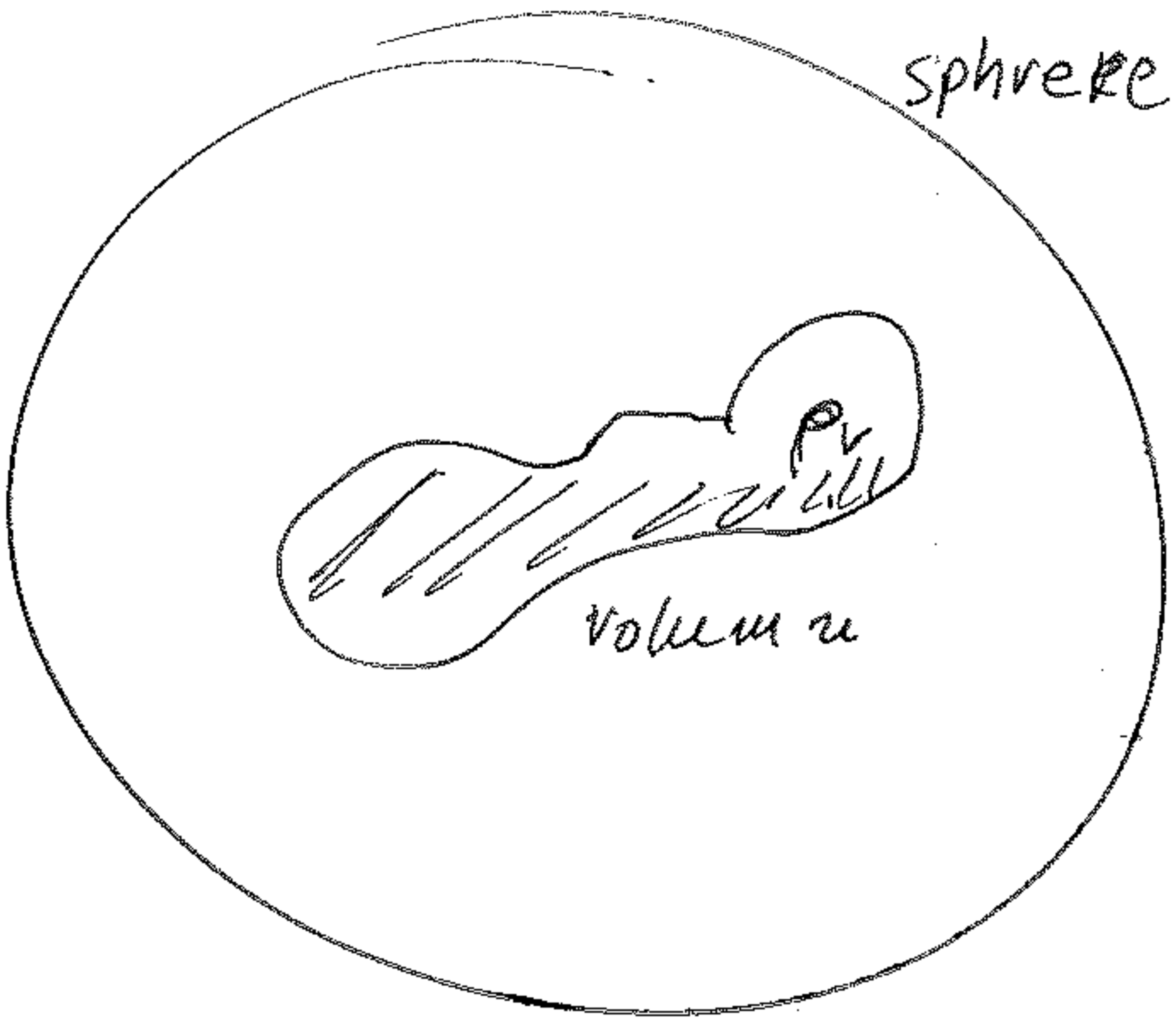
$\epsilon \bar{E} = \bar{D}$

Prove that

$$W_E = \frac{1}{2}\int \epsilon E^2 du \quad = \cancel{\frac{1}{2}\int}$$

(11)

Charge distributed through a volume u with density ρ gives rise to an electric field with $W_E = \frac{1}{2}\int_u V\rho\, du$ or $W_E = \frac{1}{2}\int \epsilon E^2 du$



$\oint \bar{D}\cdot d\bar{S} = \int \rho\, dV = Q_{encl}$

$\rho = \bar{\nabla}\cdot\bar{D}$

$\oint \bar{D}\cdot d\bar{S} = \int (\bar{\nabla}\cdot\bar{D})\, dV$

charge-containing voulum u enclosed within large sphere R, $\rho = 0$ outside u

$$W_E = \frac{1}{2}\int_u \rho V du = \frac{1}{2}\int_{\substack{\text{spherical}\\ \text{volume}}} \rho V du = \frac{1}{2}\int_{\substack{\text{sperical}\\ \text{volume}}} (\bar{\nabla}\cdot\bar{D}) V du$$

$$\nabla\cdot V\bar{A} = \bar{A}\cdot\bar{\nabla}V + V(\bar{\nabla}\cdot\bar{A}) \Rightarrow$$

$$\Rightarrow V(\bar{\nabla}\cdot\bar{A}) = \underline{\bar{\nabla}\cdot V\bar{A}} - \bar{A}\cdot\bar{\nabla}V$$

$$= \cancel{\frac{1}{2}\int \bar{V}\bar{D}} \quad = \frac{1}{2}\int (\bar{\nabla}\cdot V\bar{D}) du - \frac{1}{2}\int (\bar{A}\cdot\bar{\nabla}V) du$$

$$W_{\bar{v}} = \frac{1}{2}\int_{\text{spere}} (\bar{\nabla}\cdot V\bar{D})\,dv - \frac{1}{2}\int_{\text{spher}} (\bar{D}\cdot\bar{\nabla}V)\,dv$$

take $R \to \infty$

divergence theorem

$$\oint_{\text{surface}} V\bar{D}\cdot d\bar{S}$$

take $R \to \infty$ then the enclosed volume looks like a point charge. At the surface

$$\left.\begin{aligned} \bar{D} &\text{ appears } \sim \frac{K_1}{R^2} \\ V &\text{ appe } \sim \frac{K_2}{R} \end{aligned}\right\} \quad \text{integrant } \frac{1}{R^3}$$

$$\lim_{R\to\infty}\left(\oint_{\substack{\text{surface}\\ \cancel{R\to\infty}}} V\bar{D}\cdot d\bar{S} = \right) \qquad dS \to R^2$$

$$\lim_{R\to\infty}\left(\frac{R^2}{R^3}\right) = 0$$

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$$-\frac{1}{2}\int (\bar{D} \cdot \bar{\nabla} V)\, du =$$

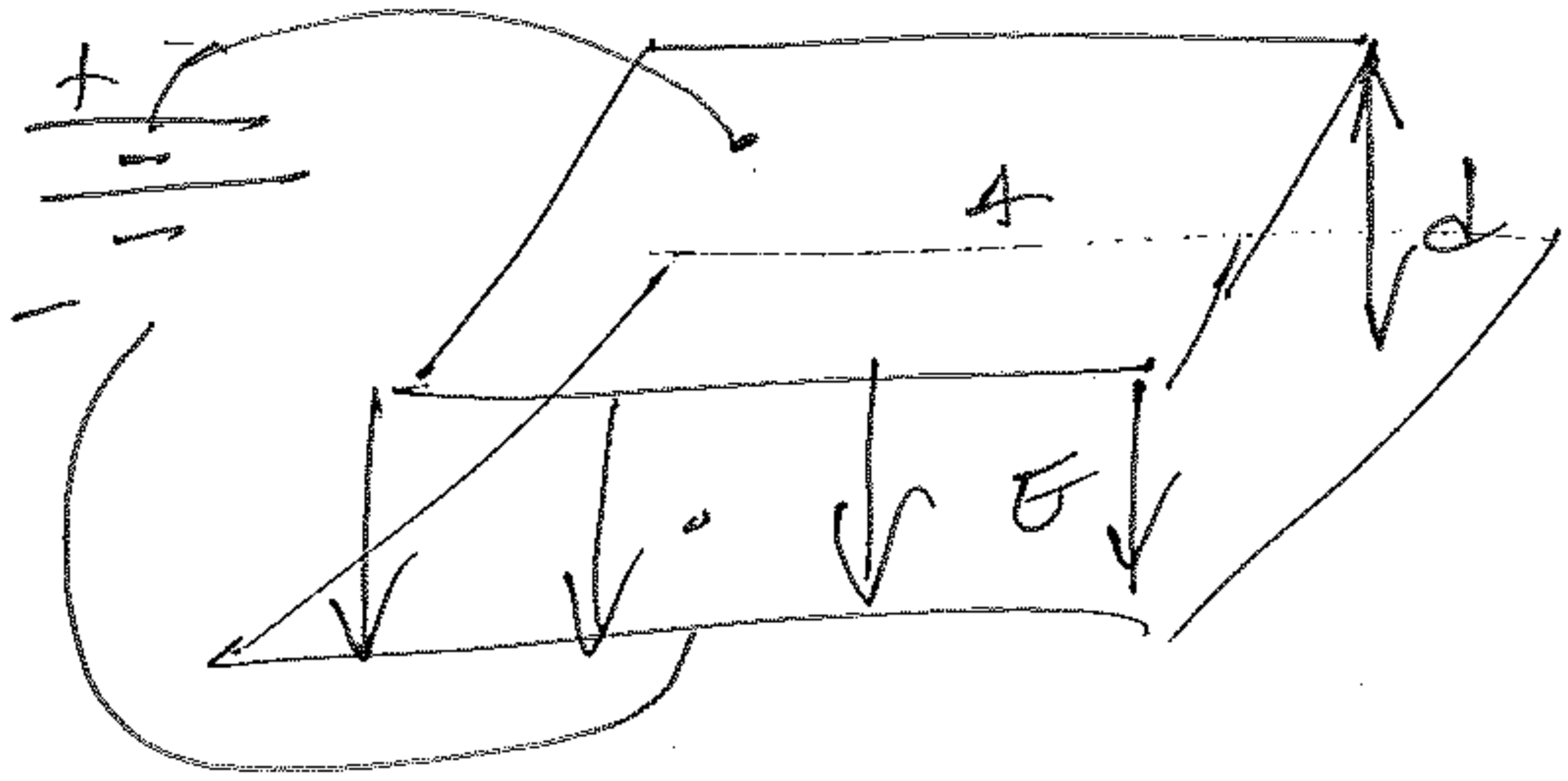
$$= \frac{1}{2}\int \epsilon \bar{E} \cdot (-\bar{E})\, du = +\frac{1}{2}\int \epsilon \bar{E}^2 du$$

Sphere $R \to \infty$

~~spherical volume~~

$$W_E = 0 + \frac{1}{2}\int \epsilon \bar{E}^2 du \quad \frac{1}{2}\left(\int \frac{\bar{D}^2}{\epsilon} du\right)$$

Example



$E = \frac{\rho}{2\epsilon_0}$

$\rho_s = \frac{dQ_s}{ds}$

A parallel plate capacitor for which $C = \epsilon \frac{A}{d}$ has a $V = ct$ across the plates.
Find the stored energy in the electric field.

→ Fringing neglected (edge effects)

$dV = -\bar{E} \cdot d\bar{l}$

$\bar{E} = -\nabla V$

$$\bar{E} = \left(\frac{V}{l}\right) \hat{a}_n \quad \text{between the plates}$$

$$= \left(\frac{V}{d}\right) \hat{a}_n \quad \text{and } E = 0 \text{ elsewhere.}$$

$$W_E = \frac{1}{2} \int_{volu} \epsilon E^2 \, dv = \frac{\epsilon}{2} \left(\frac{V}{d}\right)^2 \int_{volu} dv$$

$$= \frac{\epsilon}{2} \left(\frac{V}{d}\right)^2 A \cdot d$$

$$= \frac{\epsilon V^2 A}{2d} = \frac{1}{2} C V^2$$

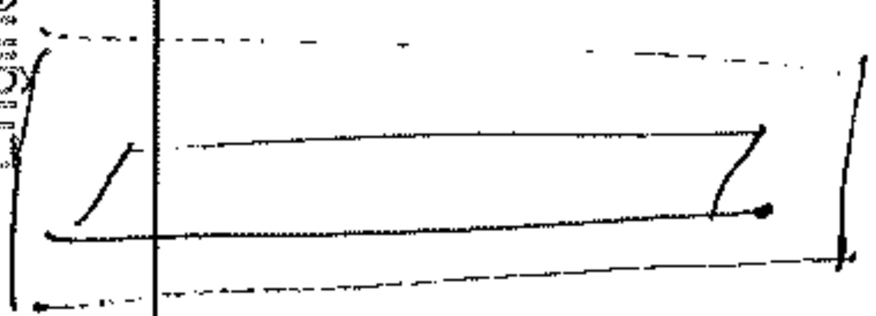
Second method

the total charge on one conductor maybe found from $\bar{D} = \epsilon \bar{E}$ at the surface via Gauss's law

$$\oint \bar{D} \cdot d\bar{S} = \int \rho \, dV = Q_{enc}$$

$$\oint \epsilon \bar{E} \cdot d\bar{S} = \int \rho \, dV = Q_{encl}$$

$$\bar{D} = \epsilon \frac{V}{d} \hat{a}_n$$



$$Q = |\bar{D}| \cdot A$$

$$= \epsilon \frac{V}{d} \cancel{\hat{a}_n} \cdot A$$

$$= \frac{\epsilon V A}{d}$$

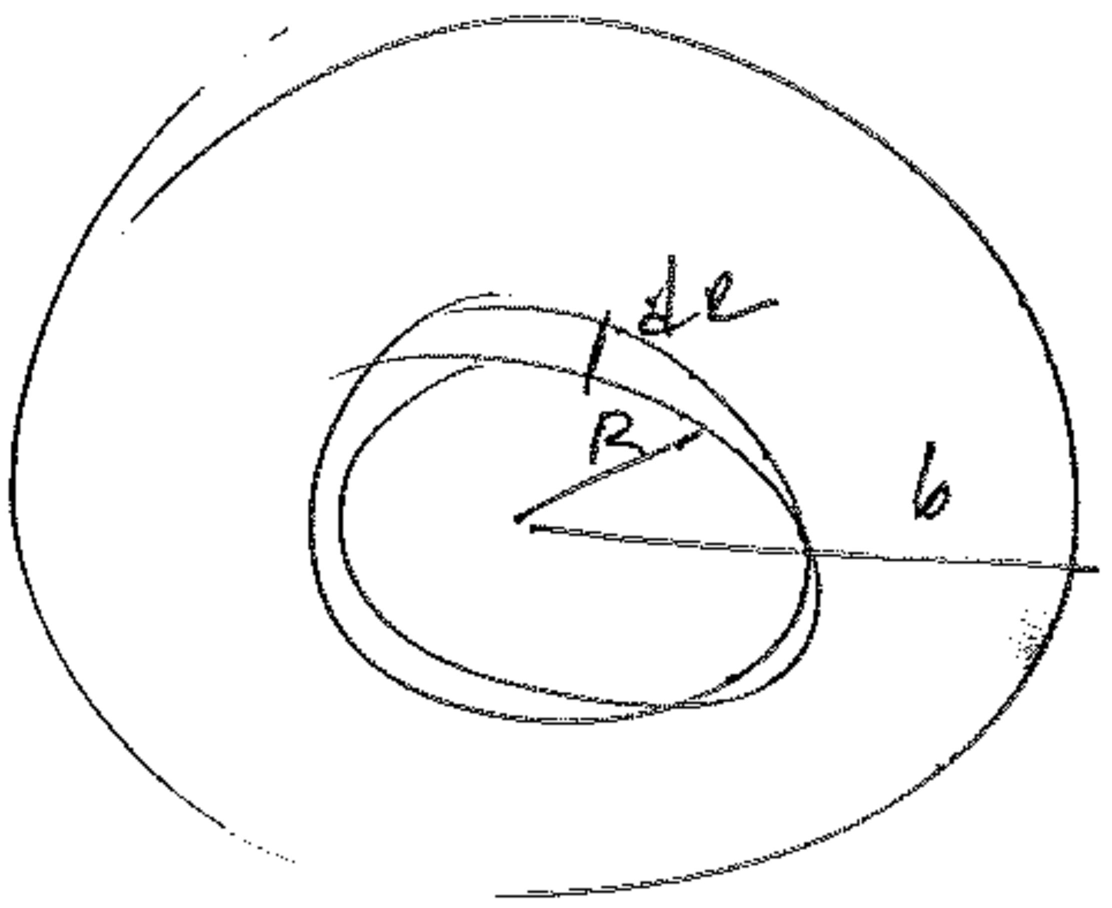
$$W = \frac{1}{2} Q V = \frac{1}{2} \frac{\epsilon V A}{d} V = \frac{1}{2} \frac{\epsilon A V^2}{2} = \frac{1}{2} C V^2$$

Potential energy of a group of N discrete point charges at rest

$$W = \frac{1}{2}\sum_{k=1}^{N} Q_k V_k$$

$$V_k = \frac{1}{4\pi\epsilon_0}\sum_{\substack{j=1\\ j\neq k}}^{N} \frac{Q_j}{R_{jk}}$$

Find the energy required to assemble a uniform sphere of charge of radius b and volume charge density ρ



Because of symmetry simple to assume that the sphere

$$V_R = \frac{Q_R}{4\pi\epsilon_0 R}$$

$$Q_R = \rho\,\frac{4}{3}\pi R^3$$

$$dQ_R = \rho\, 4\pi R^2\, dR$$

$$dW = V_R\, dQ_R = \frac{4\pi}{3\epsilon_0}\rho^2 R^4\, dR$$

Total work to assemble a uniform sphere of charge of radius b and charge density ρ is

$$\boxed{W = \int dW = \frac{4\pi}{3\epsilon_0}\rho^2 \int_0^b R^4\, dR = \frac{4\pi\rho^2 b^5}{15\epsilon_0}}\ (J)$$

$\bar{D} = \varepsilon \bar{E}$

In terms of the total charge

$$Q = \rho \frac{4\pi}{3} b^3$$

$$\boxed{W = \frac{3Q^2}{20\pi\epsilon_0 b}}$$

Energy is directly proportional to the square of the total charge and inverse proportional to the radius (could be a cloud of electrons)

for a continuous charge distribution of density ρ $\quad Q_k \to \rho\, dv$

$$W = \frac{1}{2}\int_v \rho V \, dv$$

Solve the same prob using this

$$W = \frac{1}{2}\rho\int_v V\, dv = \frac{\rho}{2}\int_0^b V 4\pi R^2 dR$$

V is the potential at point R

$$\bar{E} \begin{cases} \bar{E}_1 = \hat{a}_R E_{R1} & R = \infty \text{ to } b \\ \bar{E}_2 = \hat{a}_R E_{R2} & R = b \text{ to } 0 \end{cases}$$

$$\bar{E}_{R1} = \hat{a}_R \frac{Q}{4\pi\epsilon R^2} = \hat{a}_R \frac{\rho b^3}{3\epsilon_0 R^2} \qquad R \geq b$$

$$\bar{E}_{R2} = \hat{a}_R \frac{Q_R}{4\pi\epsilon_0 R^2} = \hat{a}_R \frac{\rho R}{3\epsilon_0} \qquad 0 \leq R \leq b$$

$$\boxed{\bar{D} = \epsilon \bar{E}}$$

$$V = -\int_{\infty}^{R} \bar{E} \cdot d\bar{R} =$$

$$= -\left[\int_{\infty}^{b} E_{R1}\, dR + \int_{0}^{R} E_{R2}\, dR\right]$$

$$= -\left[\int_{\infty}^{b} \frac{\rho b^3}{3\epsilon_0 R^2}\, dR + \int_{0}^{R} \frac{\rho R}{3\epsilon_0}\, dR\right]$$

$$= \frac{\rho}{3\epsilon_0}\left(b^2 + \frac{b^2}{2} - \frac{R^2}{2}\right) = \frac{\rho}{3\epsilon_0}\left(\frac{3}{2} b^2 - \frac{R^2}{2}\right).$$

$$W = \frac{\rho}{2}\int_{0}^{b} \frac{\rho}{3\epsilon_0}\left(\frac{3}{2} b^2 - \frac{R^2}{2}\right) 4\pi R^2\, dR$$

$$= \frac{4\pi \rho^2 b^5}{15\epsilon_0}$$

$b \to 0$ energy goes to ∞
(this is a mathematical point charge)

Strictly there are no point charges in ~~use~~ as much as the smallest charge unit, the electron is itself a distribution of charge.

Problem

Given the field $\bar{E} = \frac{K}{r} \hat{a}_r$ in cylindrical coords show that the work needed to move a point charge Q from any radial distance to a point at twice the radial distance is independent of R

$$dW = -Q\bar{E} \cdot d\bar{l} = -Q E_r dr = -\frac{KQ}{r} dr$$

$$W = -KQ \int_{r_1}^{2r_1} \frac{dr}{r} = -K \ln 2$$

independent of r_1

Problem For a line charge $\rho_\ell = \frac{10^{-9}}{2} \frac{C}{m}$ on the z axis find V_{AB} where $A = (2m, \frac{\pi}{2}, 0)$ and $B = (4m, \pi, 5m)$

$$V_{AB} = -\int_B^A \bar{E} \cdot dl \qquad \bar{E} = \frac{\rho_\ell}{2\pi\epsilon_0 r} \hat{a}_r$$

only radial $\bar{E} \cdot d\bar{l} \rightarrow E_r dr$

$$V_{AB} = -\int_B^A \frac{10^{-9}}{2(2\pi\epsilon_0 r)} dr = -9 \ln r \Big|_4^2 = 6.24V$$

Problem Given a fiel

$$\bar{E} = -\left(\frac{16}{r^2}\right)\hat{a}_r \quad \frac{V}{m}$$ is spherical coords

find the potential of poin $(2m, \pi, \pi/2)$
with respect to $(4m, 0, \pi)$

Equipotential lines are concentric spherical
shelss $r = 2m$ surface A
$r = 4m$ surface B

$$V_{AB} = -\int_2^4 \frac{-16}{r^2}\,dr = -4V$$

Problem Find the potential at $r_A = 5m$
with respect to $r_B = 15m$ due to
a point charge $Q = 500\ pC$
at the origin and zero reference @ infinit

$$V_{AB} = \frac{Q}{4\pi\epsilon}\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

$$= \frac{500\times10^{-12}}{4\pi\,(10^{-9}/36\pi)}\left(\frac{1}{5} - \frac{1}{15}\right) = 0.6V$$

$\boxed{\text{the zero reference is not needed}}$

It is needed to find V_5 and V_{15}

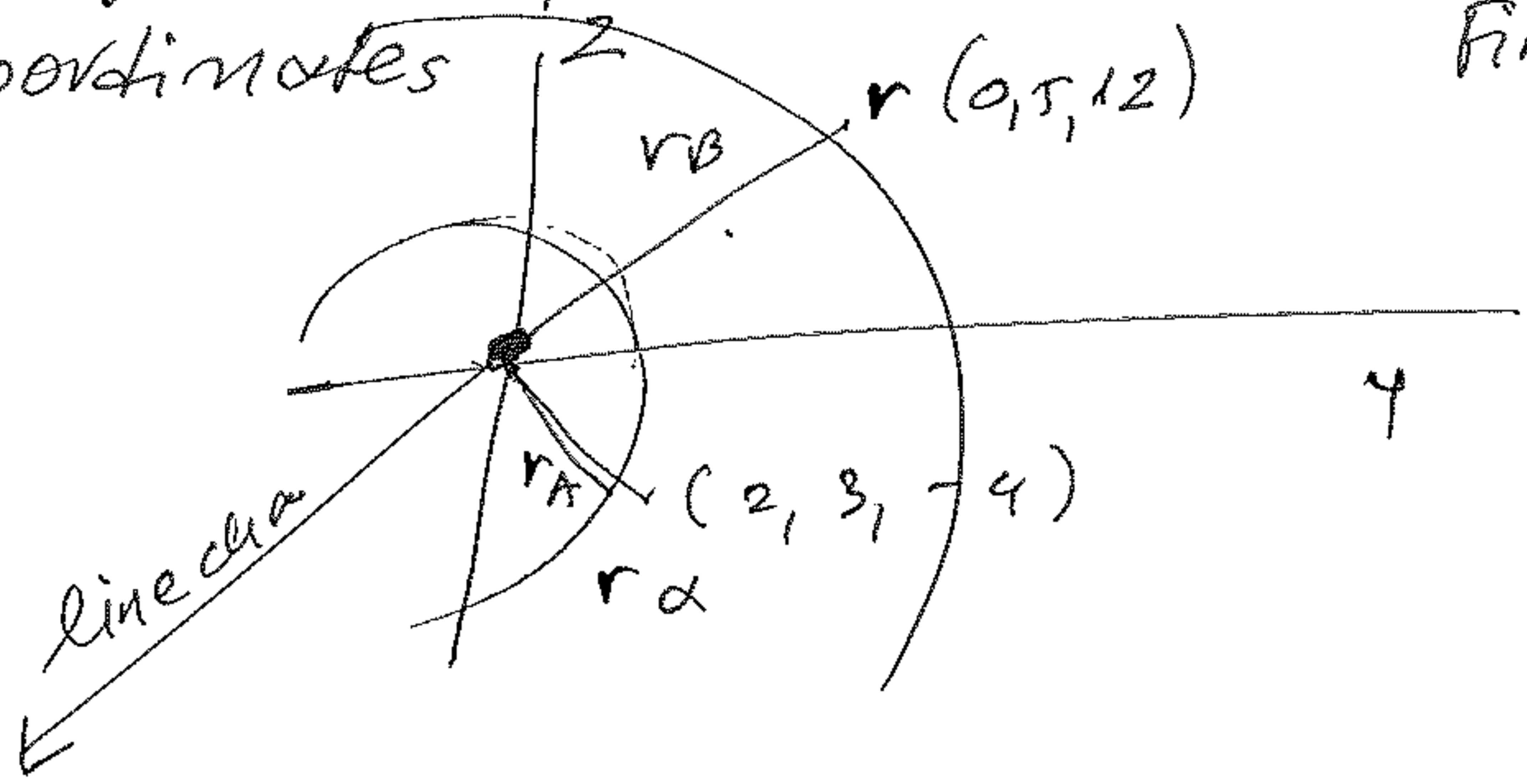
$$V_5 = \frac{Q}{4\pi\epsilon_0}\left(\frac{1}{5}\right) = 0.9\,V$$

$$V_{15} = \frac{Q}{4\pi\epsilon_0}\left(\frac{1}{15}\right) = 0.3\,V$$

$$\boxed{V_{AB} = V_5 - V_{15} = 0.6\ V}$$

Problem

A line charge ρ_ℓ lies along the x-axis and the surface of 0 potential passes through the point (0, 5, 12) m in cartesian coordinates. Find the potential at (2, 3, −4)



$$r_A = \sqrt{9+16} = 5\,m \qquad r_B = \sqrt{25+144} = 13\,m$$

$$V_{AB} = -\int_{r_B}^{r_A} \frac{\rho_\ell}{2\pi\epsilon_0 r}\,dr = -\frac{\rho_\ell}{2\pi\epsilon_0}\ln\frac{r_A}{r_B}$$

$$(= 6.88\,V)$$

No. 5505 Engineer's Computation Pad

Problem

The electric field between two concentric cylintrical conductors at $r = 0.01$ m and $r = 0.05$ m is given by $\bar{E} = \left(\frac{10^5}{r}\right) \hat{a}_r \left(\frac{V}{m}\right)$ (fringinging neglected)

Find the energy stored in a 0.5 m length assume free space

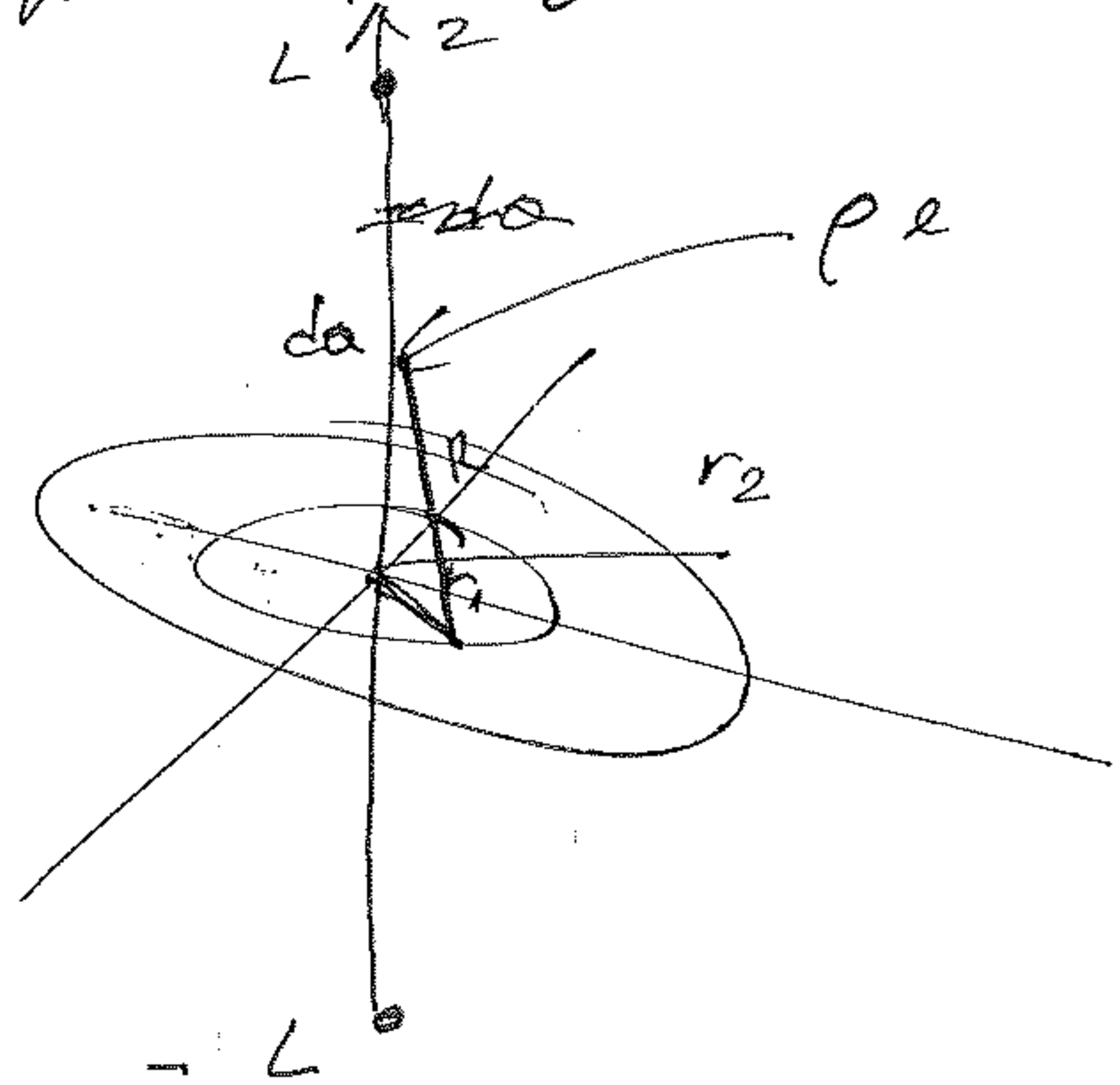
$$W_E = \frac{1}{2} \int \epsilon_0 E^2 dv =$$

$$= \frac{\epsilon_0}{2} \int_{h}^{h+0.5} \int_{0}^{2\pi} \int_{0.01}^{0.05} \left(\frac{10^5}{r}\right) r dr d\varphi dz$$

$$\left(= 0.224 \text{ J.} \right)$$

Problem

Charge is distributed uniformly along a straight line of finite length $2L$



Show that for two external points near the midpoint such that r_1 and r_2 are small compared to the length L the V_{12} is the same as for infinite line charge

point $V_1 = \displaystyle\int_0^L \frac{\rho_e dz}{4\pi\epsilon_0 (z^2+r_1^2)^{1/2}}$

$$= \frac{2\rho_e}{4\pi\epsilon_0}\left[\ln\left(z+\sqrt{z^2+r_1^2}\right)\right]_0^L$$

$$= \frac{\rho_e}{2\pi\epsilon_0}\left(\ln\left(L+\sqrt{L^2+r_1^2}\right)-\ln r_1\right)$$

$$V_2 = \frac{\rho_\ell}{2\pi\epsilon_0}\left[\ln\left(L + \sqrt{L^2+r_2^2}\right) - \ln r_2\right]$$

$L >> r_1 \qquad L >> r_2$

$$V_1 \approx \frac{\rho_\ell}{2\pi\epsilon_0}\left(\ln 2L - \ln r_1\right)$$

$$V_2 \approx \frac{\rho_\ell}{2\pi\epsilon_0}\left(\ln 2L - \ln r_2\right)$$

$$\boxed{V_{12} = V_1 - V_2 \approx \frac{\rho_\ell}{2\pi\epsilon_0}\ln\frac{r_2}{r_1}}$$

Problem

a spherical conducting shell of radius α centered at the origin has a potential field

$$V = \begin{cases} V_0 & r \leq \alpha \\ V_0 \dfrac{\alpha}{r} & r > \alpha \end{cases}$$

(with 0 reference @ infinity). Find an expression for the stored energy

$$\bar{E} = -\nabla V = \begin{cases} 0 & r < \alpha \\ V_0 \dfrac{\alpha}{r^2}\, \hat{a}_r & r > \alpha \end{cases}$$

$$W_E = \frac{1}{2}\int_{vol} \epsilon_0 E^2 dv = 0 + \frac{\epsilon_0}{2}\int_0^{2\pi}\int_0^{\pi}\int_\alpha^{\infty}\left(\frac{V_0 \alpha}{r^2}\right)^2 r^2 \sin\theta \, dr\, d\theta\, d\varphi$$

$$= 2\pi\epsilon_0 V_0^2 \alpha$$

The total charge on the shell is?

$$Q = \mathcal{E} E A = \left(\frac{\epsilon_0 V_0 \alpha}{\alpha^2}\right)(4\pi\alpha^2) = 4\pi\epsilon_0 V_0 \alpha$$

$\oint \bar{D}\cdot d\bar{S}$

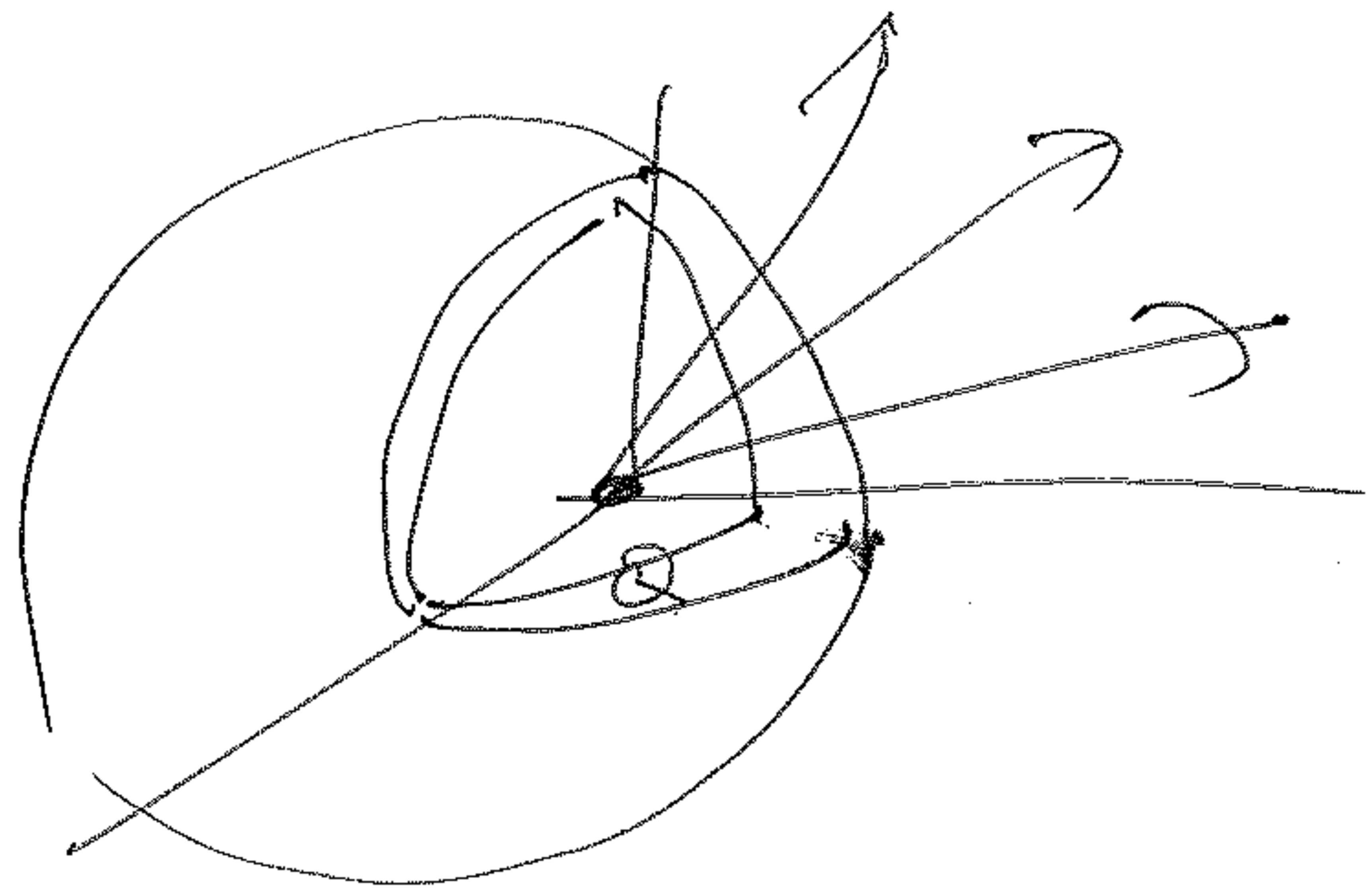
the potential @ the shell is $V = V_0 \Rightarrow W_E = \frac{1}{2} QV$

energy stored in a spherical capacitor w/ other plate @ infinity

CONDUCTORS

Under static contitions the field outside a conductor is zero both tangenial and normal components unless there exists a surface charge distribution

A surface charge does not imply a net charge in the conductor.



cosider a positive charge Q the origin of spherical coords. If the point charge is enclosed by an uncharged conducting ~~surface~~ spherical shell of finite thickness the field is

$$\bar{E} = \frac{+Q}{4\pi\epsilon_0 r^2}\hat{a}_r$$

except within the conductor where $\bar{E}=0$