$$\boxed{T \simeq \pi \times 10^7 \text{ sec}}$$

Q1 BALLOON EXPANDS OUTWARD.

$$f = \frac{\sigma^2}{2\varepsilon_0} \quad ; \quad \sigma = Q/4\pi r^2$$

TOTAL FORCE ON BALLOON: $F = fA$

$$F = \frac{\sigma^2}{2\varepsilon_0} \cdot A = \frac{\left(\frac{Q}{4\pi r^2}\right)^2}{2\varepsilon_0} \cdot 4\pi r^2 = m_B \ddot{r}$$

$$\frac{Q^2}{8\pi\varepsilon_0 r^2} = m_B \, dv/dt = m_B \, v \, dv/dr$$

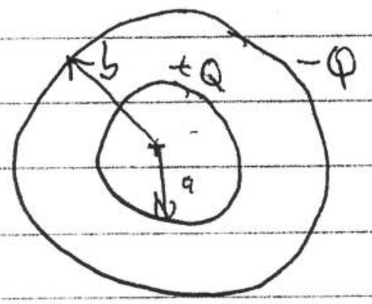
$$\frac{Q^2}{8\pi\varepsilon_0 m_B} \, dr/r^2 = v \, dv$$

$$\frac{Q^2}{8\pi\varepsilon_0 m_B} \left(-1/r\right)\Big|_{R_0}^{\infty} = \frac{v^2}{2}\Big|_0^{v_f}$$

$$v_f^2 = \frac{Q^2}{4\pi\varepsilon_0 m_B} \cdot \frac{1}{R_0}$$

$$\boxed{v_f = Q\left[\frac{1}{4\pi\varepsilon_0 m_B R_0}\right]^{1/2}}$$

Q2



$C = Q/V$ PLACE +/− Q ON THE SHELLS.

FIELD BETWEEN SHELLS:

$$\oint E \cdot dS = Q/\varepsilon_0$$

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

$$V_a - V_b = -\int_b^a \frac{Q \, dr}{4\pi\varepsilon_0 r^2}$$

$$= -\frac{Q}{4\pi\varepsilon_0}\left(-1/r\right)\Big|_{r_b}^{r_a}$$

$$V_a - V_b = +\frac{Q}{4\pi\varepsilon_0}\left(1/r_a - 1/r_b\right)$$

$$V \equiv V_a - V_b$$

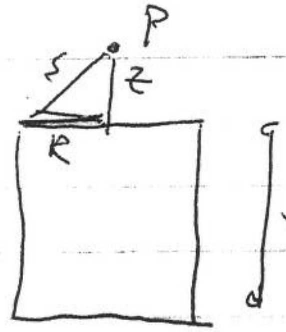
$$C = Q/V = \frac{4\pi\varepsilon_0}{(1/r_a - 1/r_b)}$$

$$\boxed{C = 4\pi\varepsilon_0 \frac{r_b r_a}{r_b - r_a}}$$

Q3

THINK OF TUBE AS STACK OF RINGS.

$$V_{1\text{-RING}} = \frac{1}{4\pi\varepsilon_0} \, dq/s$$



dq ON TUBE EXTERIOR.

$$\lambda = Q/h$$

$$V_{1\text{-RING}} = \frac{1}{4\pi\varepsilon_0} \frac{\lambda \, dz}{\sqrt{R^2+z^2}}$$

$(z=0 \ @ \ P)$

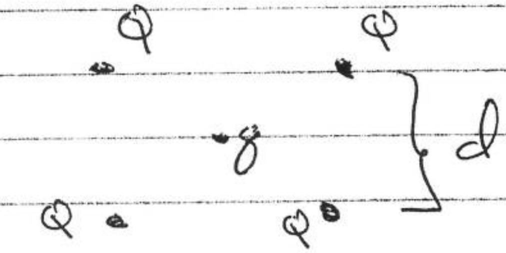
SUM OVER RINGS

$$V = \frac{1}{4\pi\varepsilon_0} \int_{z_0}^{z_0+h} \frac{\lambda \, dz}{\sqrt{R^2+z^2}}$$

$$= \frac{\lambda}{4\pi\varepsilon_0} \ln\left[\sqrt{R^2+z^2} + z\right]\Bigg|_{z_0}^{z_0+h}$$

$$\boxed{V = \frac{Q}{4\pi\varepsilon_0 h} \ln\left[\frac{\sqrt{R^2+(z_0+h)^2} + z_0+h}{\sqrt{R^2+z_0^2} + z_0}\right]}$$

Q4



FORCE ON q = ZERO BY SYMMETRY.

CALCULATE FORCE ON UPPER LEFT Q.
MUST BE ZERO.

$$F(Q\text{-UPPER LEFT}) = \frac{Q^2}{4\pi\varepsilon_0 d^2}\cdot\sqrt{2} + \frac{Q^2}{4\pi\varepsilon_0 2d^2}$$

$$+ \frac{Qq}{4\pi\varepsilon_0 d^2/2}$$

FACTOR OF $\sqrt{2}$ COMES FROM VECTOR NATURE OF FORCE FROM Q-UPPER RI[GHT] AND Q-LOWER-LEFT. TAKE F_n ALONG DIAGONAL OF SQUARE.

$$\Rightarrow \cancel{Q/\sqrt{2}} + \cancel{2q}\ \sqrt{2}\,Q + Q/2 + 2q = 0$$

$$Q/\sqrt{2} + q + Q/4 = 0$$

$$\boxed{q = -Q\left(\frac{1}{4} + \frac{1}{\sqrt{2}}\right)}$$

Q4 CONT.

$$W = \frac{1}{2} \sum q_i V_i = \frac{1}{2} \sum_{1}^{4} Q_i V_i + \frac{1}{2} q V_q$$

$$= 4\frac{Q}{2} \left\{ \frac{Q}{4\pi\varepsilon_0 d} + \frac{Q}{4\pi\varepsilon_0 d} + \frac{Q}{4\pi\varepsilon_0 \sqrt{2}\, d} + \frac{q\,Q}{4\pi\varepsilon_0\, d/\sqrt{2}} \right\}$$

$$+ \frac{1}{2} q \frac{4Q}{4\pi\varepsilon_0\, d/\sqrt{2}}$$

$$= 2Q^2 \frac{1}{4\pi\varepsilon_0 d} \left\{ 1 + 1 + \frac{1}{\sqrt{2}} - \sqrt{2}\left(\frac{1}{4} + \frac{1}{\sqrt{2}}\right) \right\}$$

$$- \frac{2Q^2}{4\pi\varepsilon_0 d} \cdot \sqrt{2} \left(\frac{1}{4} + 1/\sqrt{2} \right)$$

$$= \frac{2Q^2}{4\pi\varepsilon_0 d} \left\{ 2 + \frac{1}{\sqrt{2}} - 1 - \frac{1}{2\sqrt{2}} - 1 - \frac{1}{2\sqrt{2}} \right\}$$

$$\boxed{W = 0}$$