Solution

Part 1a

a.

$$v_{ret} = \sqrt{v_0^2 - 2(e/m)V} = 1.956 \times 10^6\, m/s$$

$$v_{acc} = \sqrt{v_0^2 + 2(e/m)V} = 2.044 \times 10^6\, m/s$$

(0.5 pts)

$$x_{ret} = v_{ret}t, \qquad \mathrm{x_{acc}} = v_{acc}\,(t - T/2)$$

(0.5 pts)

$$x_{ret} = x_{acc} \rightarrow \mathrm{t_{bunch}} = \frac{v_{acc}T}{2(v_{acc} - v_{ret})} = 11.61\,T$$

(0.3 pts)

$$b = v_{ret}t_{bunch} = 2.272 \times 10^{-2}\, m.$$

(0.2 pts)

b. The phase difference:

$$\Delta\varphi = \pm\left(\frac{t_{bunch}}{T} - n\right)2\pi = \pm\mathbf{0.61} \times 2\pi = \pm\mathbf{220}^\circ.$$

(1.0 pts)

OR

$$\Delta\varphi = \pm\mathbf{140}^\circ$$

Part 1b

$$\rho_L = n_L\frac{M}{N_A}$$

(0.3 pts)

where $\mathrm{n_L}$ is the number of molecules per cubic meter in the liquid phase

Average distance between the molecules of water in the liquid phase:

$$d_L = (n_L)^{-1/3} = \left(\frac{M}{\rho_L N_A}\right)^{1/3}$$

(0.2 pts)

$\mathrm{P_aV = nRT}$,

where n is the number of moles (0.6 pts)

$$P_a = \frac{nM}{V}\frac{RT}{M} = \rho_V\frac{RT}{M} = \frac{n_V M}{N_A}\frac{RT}{M}$$

where $\mathrm{n_V}$ is the number of molecules per cubic meter in the vapor phase. (0.9 pts)

$$d_V = (n_V)^{-1/3} = \left(\frac{RT}{P_a N_A}\right)^{1/3}$$

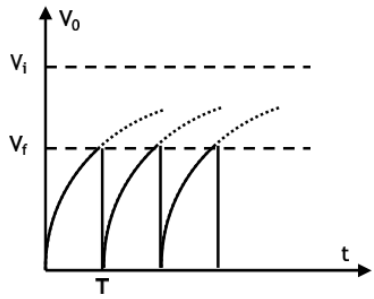
(0.2 pts)

$$\frac{d_V}{d_L} = \left(\frac{RT\rho_L}{P_a M}\right)^{1/3} = 12$$

(0.3 pts)

Part 1c

a. (0.5 pts.)



b. $V_i >> V_f$ (0.2 pts)

c.

$$V_f = V_i \left(1 - e^{-T/RC}\right)$$

(0.2 pts)

If

$$V_i >> V_f, \qquad T/RC << 1, \qquad e^{-T/RC} \approx 1 - (T/RC)$$

then

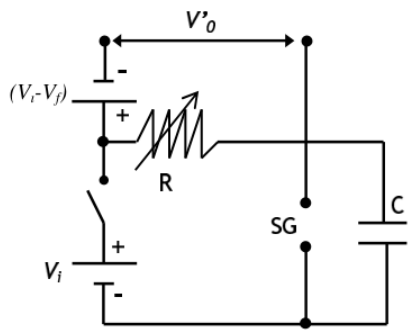
$$T = (V_f/V_i)\, RC$$

(0.2 pts)

d. R (0.2 pts)

e. SG and R (0.2 pts)

f. Correct circuit (0.4 pts)



V_0' (0.3 pts)

$V_i' - V_f$ with the correct polarity (0.3 pts)

Total (1.0 pts)

Part 1d

As the beam passes through a hole of diameter D the resulting uncertainty in the y-component of the momentum;

$$\Delta p_y \approx \frac{\hbar}{D}$$

(0.6 pts)

and the corresponding velocity component;

$$\Delta v_y \approx \frac{\hbar}{MD}$$

(0.4 pts)

Diameter of the beam grows larger than the diameter of the hole by an amount

$$\Delta \mathrm{D} = \Delta \mathrm{v_y}.\mathrm{t},$$

where t is the time of travel. (0.2 pts)

If the oven temperature is T, a typical atom leaves the hole with kinetic energy

$$KE = \frac{1}{2}Mv^2 = \frac{3}{2}kT$$

(0.4 pts)

$$v = \sqrt{\frac{3kT}{M}}$$

(0.2 pts)

Beam travels the horizontal distance L at speed v in time

$$t = \frac{L}{v},$$

so (0.2 pts)

$$\Delta D = t\,\Delta v_y \approx \frac{L}{v}\,\frac{\hbar}{MD} = \frac{L\hbar}{MD\sqrt{\frac{3kT}{M}}} = \frac{L\hbar}{D\sqrt{3MkT}}$$

(0.4 pts)

Hence the new diameter after a distance L will be;

$$\mathrm{D_{new}} = \mathrm{D} + \frac{L\hbar}{D\sqrt{3MkT}}$$

(0.1 pts)