21.2

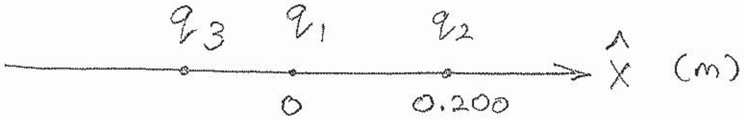
Current $= 20,000\ C/s \equiv I$

and $t = 100\ \mu s = 10^{-4}\ s$

$$Q = It = 2.00\ C$$

$$n_e = \frac{Q}{1.60 \times 10^{-19} C} = 1.25 \times 10^{19}$$

21.19



$\vec{F}_2$ is in the $+\hat{x}$ direction

$$F_2 = k\frac{|q_1 q_2|}{r_{12}^2} = 3.37\ N, \text{ so } F_{2x} = +3.37N$$

$$F_x = F_{2x} + F_{3x} \quad \text{and} \quad F_x = -7.00\ N$$

So $F_{3x} = F_x - F_{2x} = -7.00N - 3.37N = -10.37N$

For F_{3x} to be negative, q_3 must be on the $-\hat{x}$ axis. So

$$F_3 = k\frac{|q_1 q_3|}{r_{13}^2} \quad \text{and} \quad |x| = \sqrt{\frac{k|q_1 q_3|}{F_3}} = 0.144m$$

So $x = -0.144m$

21.28

(a) $x = \frac{1}{2}at^2$

$$a = \frac{2x}{t^2} = \frac{2(4.50\ \text{m})}{(3.00\times10^{-6}\ \text{s})^2}$$

$$= 1.00 \times 10^{12}\ \text{m/s}^2$$

$$E = \frac{F}{q} = \frac{ma}{q} = \frac{(9.11\times10^{-31}\ \text{kg})(1.00\times10^{12}\ \text{m/s})}{1.6\times10^{-19}\ \text{C}}$$

$$= 5.69\ \text{N/C}$$

The force is up, so the electric field must be downward since the electron is negative.

(b) The e^-'s acceleration is $\sim 10^{11} g$ (!), so gravity is negligibly small compared to qE.

21.50

Calculate in vector form the electric field for each charge, and add them.

$$\vec{E}_2 = \frac{-1}{4\pi\varepsilon_0}\frac{6.00\times10^{-9}\ \text{C}}{(0.6\ \text{m})^2}\hat{i}$$

$$= -150\,\hat{i}\ \text{N/C}$$

$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}(4.00\times10^{-9}\ \text{C})\left[\frac{0.6}{(1.00\ \text{m})^2}\hat{i} + \frac{0.8}{(1.00\ \text{m})^2}\hat{j}\right]$$

$$= (21.6\,\hat{i} + 28.8\,\hat{j})\ \text{N/C}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2$$

and $E = |\vec{E}| = \sqrt{(128.4)^2 + (28.8)^2} = 131.6\ \text{N/C}$

and $\tan\theta = \frac{28.8}{128.4} \Rightarrow \theta = 12.6^\circ$ up from $-\hat{x}$.

21.68

for each ball, in the horizontal direction,

$$\Sigma F_x = T\sin\theta - F_e = 0$$

and in the y-direction,

$$\Sigma F_y = T\cos\theta - mg = 0$$

so $$\frac{mg\sin\theta}{\cos\theta} = F_e = \frac{kq^2}{d^2}.$$

But $$\tan\theta \simeq \frac{d}{2L},$$

so $$d^3 = \frac{2kq^2L}{mg}$$

$$d = \left(\frac{q^2L}{2\pi\varepsilon_0 mg}\right)^{1/3}.$$

21.89

(a) On the x-axis, at position $(a+r)$,

$$dE_x = \frac{1}{4\pi\varepsilon_0}\frac{dq}{(a+r-x)^2} \quad \text{where } dq = \frac{Q}{a}\cdot dx$$

so $$E_x = \frac{1}{4\pi\varepsilon_0}\int_0^a \frac{Q\,dx}{a(a+r-x)^2}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Q}{a}\left(\frac{1}{r} - \frac{1}{a+r}\right).$$

$$E_y = 0.$$

(b) $$\vec{F} = q\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{a}\left(\frac{1}{r} - \frac{1}{a+r}\right)\hat{i}$$

(c) If $r \gg a$, $$F = \frac{kqQ}{ar}\left[\left(1 - \frac{a}{r}\right)^{-1} - 1\right]$$

$$= \frac{kqQ}{ar}\left[1 + \frac{a}{r} + \cdots - 1\right]$$

$$\approx \frac{kqQ}{r^2}$$

Q looks like a point from far away.

$$\frac{1}{1+x} = 1 - x + x^2 - x^3 + \ldots = \sum_{k=1}^{\infty} (-1)^{k-1} x^{k-1}$$

$$(1+x)^q = \underbrace{\underbrace{1 + qx}_{} + \frac{q(q-1)}{2!} x^2}_{} + \ldots \quad \frac{q(q-1)\ldots(q-k+1)}{k!} x^k \ldots$$

$$\sin\theta = \sum_{k=0}^{\infty} (-1)^k \frac{x^{2k+1}}{(2k+1)!}$$

$$= \theta - \frac{1}{6}\theta^3 + \frac{1}{120}\theta^5 - \ldots$$

$$\simeq \theta$$

$$1.000\times10^{-4} \times 101 = \overbrace{1.00}^{\text{3 sig fig}}\times10^{-4} \times \overbrace{1.01}^{\text{2 sig fig}}\times10^{+2} = \cancel{1.00010}$$

$$= \cancel{1.01\times10}^{-2}$$

$$= 1.000\times 1.01 \times10^{-2}$$

$$= \underbrace{1.01}_{}\times10^{-2}$$

21.104

(a) $Q = A\sigma = \pi(R_2^2 - R_1^2)\sigma$

(b) From Eq. (21.11), the electric field from a disk is $E = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{1}{\sqrt{(R/x)^2+1}}\right]$,

so $$\vec{E}(x) = \frac{\sigma}{2\varepsilon_0}\left\{\left[1 - \frac{1}{\sqrt{(R_2/x)^2+1}}\right] - \left[1 - \frac{1}{\sqrt{(R_1/x)^2+1}}\right]\right\}\frac{|x|}{x}\hat{\imath}$$

$$\therefore \vec{E}(x) = -\frac{\sigma}{2\varepsilon_0}\hat{\imath}\left\{\frac{1}{\sqrt{(R_2/x)^2+1}} - \frac{1}{\sqrt{(R_1/x)^2+1}}\right\}\frac{|x|}{x}$$

(c) Note that $\frac{1}{\sqrt{(R_1/x)^2+1}} = \frac{|x|}{R_1}\left[1 + \left(\frac{x}{R_1}\right)^2\right]^{1/2}$

$$\approx \frac{|x|}{R_1}\left\{1 - \frac{(x/R_1)^2}{2} + \cdots\right\}$$

$$\Rightarrow \vec{E}(x) = \frac{\sigma}{2\varepsilon_0}\left(\frac{x}{R_1} - \frac{x}{R_2}\right)\frac{x}{|x|}\hat{\imath}$$

$$= \frac{\sigma}{2\varepsilon_0}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)\frac{x}{|x|}2\hat{\imath}$$

Sufficiently close $\Rightarrow \left(\frac{x}{R_1}\right)^2 << 1$.

(d) $F = qE(x) = -\frac{q\sigma}{2\varepsilon_0}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)x$

$$= m\ddot{x}$$

so $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{q\sigma}{2\varepsilon_0 m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$