Problem 1: (C)

Ampere's Law: $B = \mu_0 I/(2\pi r)$

The direction is given by the right hand rule. On the x axis, for positive x, B due to all wires points into the y-direction. The perpendicular distance r of point (x, 0, 0) from the diagonal wires is $x/\sqrt{2}$, and from the horizontal wire it is x. $B = 2\sqrt{2}\, \mu_0 I/(2\pi x) + \mu_0 I/(2\pi x)$.

Problem 2: (D)

Capacitance: $C = Q/V$, $V = Q/C$, $C = \varepsilon_0 A/d$. $E = V/d = Q/(\varepsilon_0 A)$. $dE/dt = 9/(8.85*10^{-12} *0.25)$ V/m

Problem 3: (B)

The Lorentz force: $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$.

$qvB = mv^2/r$, $r = mv(qB)$, r is proportional to v.

Problem 4: (E)

Lenz's rule

The magnetic field near the poles points in the direction from S to N.

Problem 5: (D)

AC circuits

At low frequencies the capacitor behaves like an open circuit and at high frequencies it behaves like a short circuit.

Problem 6: (D)

Resistors in series and parallel

I = (½ + ¼ + ¾)A = 1.5 A, V = 3 V + 15 V = 18 V.

Problem 7: (D)

Gauss' Law: $E = kQ/r^2$ in region 1, E = 0 in region 2

$V(r) = -\int_a^r \mathbf{E}\cdot d\mathbf{r} + V(a)$

$V(r) = -\int_a^r (kQ/r^2)dr = kQ(1/r - 1/a)$ in region 1

$V(r) = kQ(1/b - 1/a)$ in region 2

Problem 8: (E)

Coulomb's Law: $\mathbf{E} = kQ\mathbf{r}/r^3$

The horizontal components of the fields due to the two charges add, the vertical components cancel. (dipole field proportional to $1/r^3$)

Problem 9: (C)

Vector calculus

Problem 10: (E)

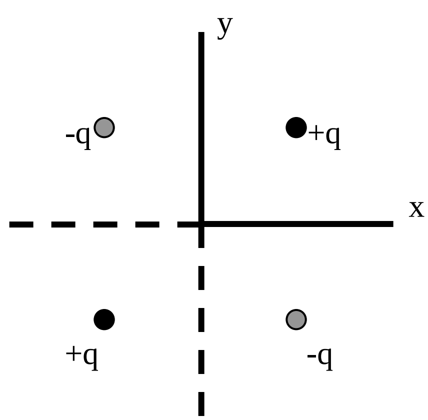
Gauss' law: total flux = Q_{inside}/ε_0

total flux = $10^{-9}/(8.85*10^{-12}) \sim 100\ Nm^2/C$
Flux through rest of surface = $100\ Nm^2/C - (-100\ Nm^2/C)$

Problem 11: (A)
Gauss' law, properties of conductors

Problem 12: (E)
Ampere's law: $B = \mu_0 I_{through\ loop}/(2\pi r)$, between R and 2R $I_{through\ loop}$ increases linearly from 0 to I_{total}.

Problem 13: (E)
Method of images: The force is the vector sum of the forces due to the image charges.



$$\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 = \frac{q^2}{a^2}\left(-\frac{1}{4}\mathbf{i} - \frac{1}{4}\mathbf{j} + \frac{\sqrt{2}}{16}\mathbf{i} + \frac{\sqrt{2}}{16}\mathbf{j}\right) = -\frac{q^2}{4a^2}\left(1 - \frac{\sqrt{2}}{4}\right)(\mathbf{i} + \mathbf{j})$$

$$F = \frac{q^2}{4a^2}\left(1 - \frac{\sqrt{2}}{4}\right)\sqrt{2} = \left(\frac{\sqrt{2}}{4} - \frac{1}{8}\right)\frac{q^2}{a^2}$$

Problem 14: (D)
Transformers: For a transformer $V_p/N_p = V_s/N_s$.
Check: For an ideal transformer we have $P = V_pI_p = V_sI_s$. $I_p/I_s = N_s/N_p$.
$Z_p = V_p/I_p = (N_p/N_s)^2(V_s/I_s) = (N_p/N_s)^2R$, so (E) is correct.

Problem 15: (B)
Energy stored in a capacitor: $U = (1/2)(Q^2/C) = (1/2)CV^2$
Here V is constant, $C = \varepsilon_0 A/d \rightarrow C = \kappa\varepsilon_0 A/d$.