Midterm Exam
Physics 120a
Spring 2006

1 Hour,
Closed Book,
No Notes, Calculators OK

Prob 1 [15 pts] _____________
Prob 2 [ 8 pts] _____________
Prob 3 [12 pts] _____________
Prob 4 [15 pts] _____________
Total [50 pts] _____________
10. a) For a room-temperature diode conducting 1.0 mA, about what increase in voltage $\Delta V_D$ would cause it to conduct 10.0 mA?

\[ I = I_R \left( \frac{1 \text{ eV}}{kT} - 1 \right) \]

\[ e^{\frac{\Delta V}{kT}} \times 10 \times \]

\[ kT \approx \frac{1}{40} \text{ eV} \]

\[ \frac{e^{\Delta V}}{kT} \times 2 \Rightarrow \Delta V \approx \frac{2}{40} V = 50 \text{ mV} \]

b) Your car is out of gas, but your Sears DieHard battery promises 17.50 Ampere-hours. How far up a gentle hill will your electric starter motor pull your 10.5-ton car?

\[ E = \alpha V \]

\[ = \alpha V \times 6.34 \text{ Joules} \]

\[ = 175 \text{ Amp} \cdot \text{hr} \times \frac{3600 \text{ s}}{1 \text{ hr}} \times 12 \text{ V} \]

\[ = 7.56 \times 10^6 \text{ Joules} \]

\[ \text{7.56 Jelly donuts} @ 250 \text{ Calories each} \]

\[ E_{\text{pot}} = mgh \]

\[ = 10.53 \text{ kg} \times 9.8 \text{ m/s}^2 \times 10.54 \text{ hr} \]

\[ = 10.54 \text{ hr} \]

\[ h = \frac{7.56 \times 10^6}{1.5 + 4} = 500 \text{ m} \]
A "quantum dot" is a 50 nm x 50 nm x 10 nm metal patch, deposited on top of a 1 μm thick insulator with dielectric $\varepsilon = \varepsilon_0$, with a metal ground plane on the bottom of the insulator. About how many electrons (factor-of-2) must be deposited on the dot to raise its potential to 2.0 volts?

$\varepsilon = \varepsilon_0$

$Q = \frac{kQ}{r} = \frac{9.4 + q}{50 \times 9}$

$Q = 2 \times 50 - 9

= 11.18 \text{ Coul} \left( \frac{1e^-}{1.6 \times 10^{-19} \text{ Coul}} \right)$

= 70 electrons

Note: $C = \varepsilon_0 \frac{A}{d}$ would give $C = 2a - 2l$!!

$\# = \frac{Q}{e} = \frac{CV}{e} = \frac{(2a - 2l)(2)}{1.6 \times 10^{-19}}$

= 28
2. Given an Ammeter with 100 μA Full Scale sensitivity and resistance $R_{\text{int}} = 0.1 \Omega$; Design a circuit to measure currents of $0 \to 100$ μA. The circuit should be "real," i.e., not incorporating ridiculously small or large resistors, and can generate a voltage drop of up to 1.0 Volt.

\[ R_0 \times 10.\text{A} = 100,\mu\text{A} \times 0.1 \Omega \]
\[ R_0 = \frac{1.0 \Omega \times 10^{-5}}{10^6 \Omega} = 10^{-9} \Omega \]

"ridiculously" small

Back voltage presented to outside world:
\[ \Delta V_{\text{back}} = 100 \times 10^{-6} R_{\text{int}} \]
\[ = 10. \mu \text{V} = \text{unnecessarily small} \]

For $\Delta V_{\text{back}} = 1.0 \text{V}$, $R_{\text{int}} = 10^4 \Omega$!!

Better
\[ V_{\text{back}} = 1.0 \]
\[ \text{Motor is more "ideal" than you want}!! \]
a cylinder of material has Resistance \( R = \rho \frac{L}{A} \), where \( \rho \) is the Resistivity of the material.

Your fluids textbook says that the pressure drop \( \Delta P \) from a flow \( F \) in a pipe of length \( L \) and diameter \( D \) is given by

\[
\Delta P = \frac{128}{\pi} F L \frac{D^4}{A^4} \quad \text{with} \quad \nu = 1 \times 10^{-6} \text{ m}^2/\text{s} \quad \text{the viscosity of water.}
\]

a) Derive a formula for the "Resistivity" of a pipe.

b) Why does this "Resistivity" depend on diameter? \( A = \frac{\pi}{4} D^2 \)

Water: \( R = \frac{\Delta P}{F} = \frac{128}{\pi} \frac{L}{D^4} \)

\[
= \frac{128}{\pi} \frac{L}{\frac{\pi}{4} D^2} \approx \frac{32 D^{-2}}{\sqrt{\frac{\nu}{F_{\text{fluid}}}}} \]

The resistivity depends on \( D \) because water is "resisted" only by sticking to the walls; bigger pipes have much lower "resistivity".

Electricity flow is resisted uniformly across area \( A \), i.e., by the resistivity of the material.

c) Derive the Capacitance of a vertical cylindrical tank of water.

\[
C = \frac{Q}{P} \quad Q = \text{Mass [kg]}
\]

\[
M = Q = \frac{A \cdot h \cdot 10^3 \text{ kg/m}^3}{1}
\]

\[
P = \frac{\text{Force}}{A} = \frac{Mg}{A} = \frac{h (9.8) 10^3}{A} \approx 10^4 h
\]

\[
C = \frac{\frac{Q}{P}}{10^4 h} = \frac{A}{10}
\]
4. a) Design a Hi-Pass RC filter with corner frequency $f_c = 20 \text{kHz}$ and input impedance $\approx 10 \text{k}\Omega$ at $f > 20 \text{kHz}$.

b) Draw the Bode plot of magnitude and phase of $\frac{V_{out}}{V_{in}}$ for $1 \times f < 10^6 \text{ Hz} \Rightarrow 10^{-3} < \text{magnitude} < 1$.

c) Sketch the modified $\frac{V_{out}}{V_{in}}$ you would actually observe with a 3 ft coax cable (30 pF/ft) to your (1 MHz) scope.

2. $R = 10 \text{k}\Omega$

$\omega_c = \frac{f_c}{R} = \frac{1}{\omega C} = \frac{1}{2\pi (2\pi + 3)}$

$C = \frac{1}{10 + 3} \frac{1}{2\pi} \frac{2\pi + 3}{2\pi + 3} = \frac{1}{120} \text{ uF} = 8 \text{ nF}$

3. $C = \frac{1}{2\pi f} \Rightarrow 100 \text{ Hz} \Rightarrow 10 \text{ kHz}$

$X_c = \frac{L}{\omega C} = \frac{1}{2\pi f 100 \text{ Hz}} = 10 \text{ kHz}$ at $f = \frac{1}{2\pi 10 \text{ kHz}}$

$\frac{1}{8 \text{ MHz}}$

$\frac{1}{4 \text{ MHz}}$

Down by $\frac{1}{80}$ above $f_2 = \frac{1}{8 \text{ MHz}}$

$Q = +90 \degree$ (output leads)