UNIVERSITY OF MANITOBA

April 17, 2012 — FINAL EXAM

DEPARTMENT & COURSE NO.: PHYS 2610 — TIME: 3 hours

EXAMINATION: Circuit Theory and Introductory Electronics — EXAMINER: S. A. Page

Instructions: Answer all questions. Be as concise as possible with descriptive answers. Define variables clearly with reference to a labeled diagram. Ask for assistance if you require a formula that is not explicitly provided on the sheet. **All questions are of equal weight.**

1. LED Circuit

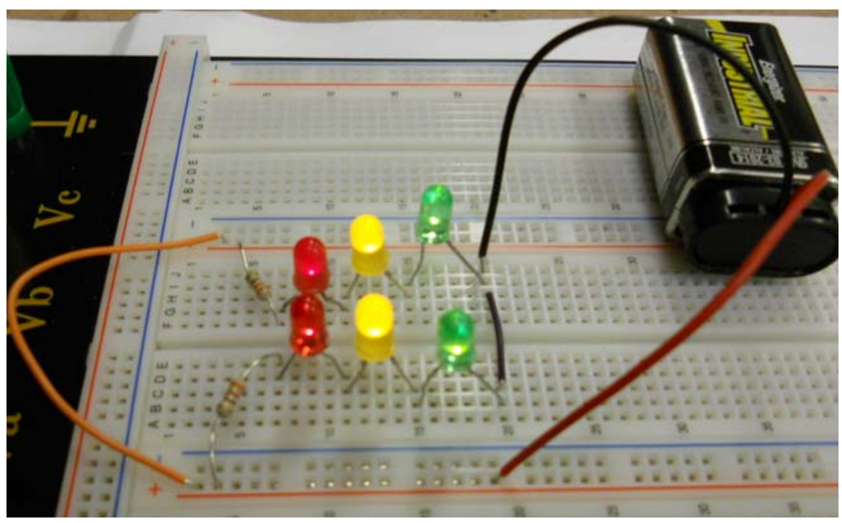
a) Draw an energy level diagram to indicate the conduction and valence band energies in a pn junction diode under an applied forward bias that is just sufficient to turn it on.

Also indicate the bias voltage polarity and the direction of current flow through the device under these conditions, as well as the direction of motion of the majority charge carriers in each region.

In a light-emitting diode (LED), the recombination of electrons and holes inside the pn junction produces visible light. Illustrate this process using the diagrams you have just drawn.

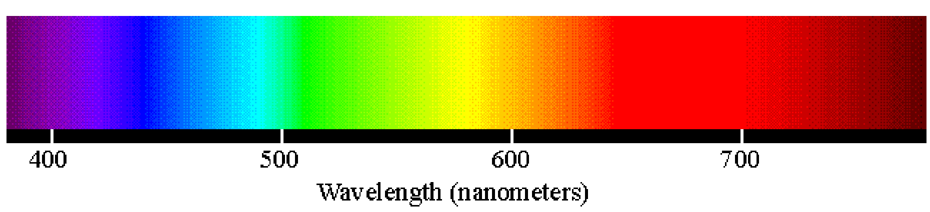
b) Draw a circuit diagram to represent the components arranged in the photograph. The battery is 9 V and the resistors are 330 Ω.

LED circuit symbol: 



c) Estimate the voltage dropped across each LED in the circuit. To do this, note that energy of a photon is given by $E = hc/\lambda$ where $hc = 1240\ \text{eV nm}$, and the visible spectrum is illustrated below.

Visible spectrum →



d) Calculate the total current flowing through the battery, taking into account your results for part c). If the battery has a charge rating of 400 mA.hr, i.e. if it provides a constant EMF of 9 V for that much charge flowing through it, how long will the LED's stay lit?

e) After the battery has delivered 99% of its charge rating at 9 V, its properties change dramatically, and it behaves like a capacitor which discharges through the circuit shown.

What value of C describes the battery in this final discharge cycle, assuming that 1% of its initial charge remains at the start of this process?

Sketch the equivalent circuit for this case, assuming that the diodes are initially on, and write down Kirchoff's laws to find a differential equation for $Q(t)$, the charge remaining on the equivalent capacitor as a function of time. *Assume the battery starts behaving like a capacitor at* $t = 0$, *to simplify the math.*

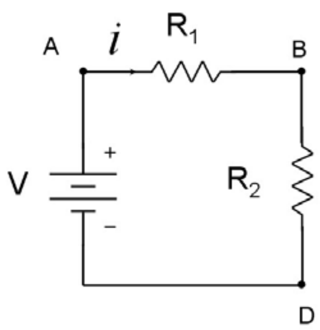
What is the effective RC time constant of this circuit?

f) At what value of $Q(t)$ will the LED's turn off?

2. Measuring Things

a) Briefly, what does a DMM do when it measures resistance? What, if any, precautions should be taken when measuring resistances in a circuit in order to ensure reliable results?

b) In the circuit shown, we wish to measure the current i.



Draw the circuit showing how the DMM should be connected in order to directly measure i.

Specify the connections at the front of the DMM as well as the DMM selector knob setting.

What, if anything, is assumed about the DMM in order to obtain an accurate result?

c) For the circuit of part b), the component values are $V = 10$ V, $R_1 = 1 M\Omega$, $R_2 = 100\ k\Omega$. What value of i is expected in this case?

d) The smallest current we can measure directly with our DMM is 0.1 mA. In DC voltage mode, the DMM has an internal resistance of about 10 MΩ.

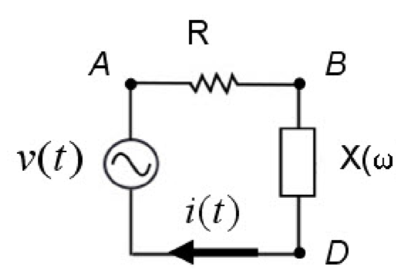
Draw the circuit showing how the DMM should be connected for a measurement with the aim of obtaining an accurate value of the current i with these component values. Specify the connections at the front of the DMM as well as the DMM selector knob setting.

Derive an algebraic formula that relates the meter reading to the correct value of i, i.e. the value of current flowing in the circuit when there is no meter present. *(You don't need to work out the numbers.)*

e) When the DMM is connected to measure voltage, and the selector knob is set to the symbol $\tilde{V}$ (AC V), it measures the RMS potential difference across the input, V_{RMS}.

State the general definition of V_{RMS} for a periodic waveform with period T, and use it to work out the relation between V_{RMS} and the amplitude V_o for a square wave with mean value $\langle V(t) \rangle = 0$.

f) Suppose we want to study the phase ϕ of the current $i(t)$ in a series circuit relative to the sinusoidal AC voltage $v(t)$ applied as shown.

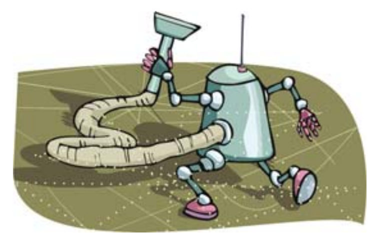


Draw the circuit diagram and indicate the ground and scope probe connections explicitly that will display the $v(t)$ waveform on channel 1 and the AC current waveform on channel 2.

Use point form to indicate briefly the most important elements of the scope set up to perform the phase measurements of interest.

With the scope set up accordingly, draw a sketch of the channel 1 and channel 2 waveforms; indicate the quantities you need to record in order to determine ϕ, and indicate how to work out its value in radians from these data.

3. Grab Bag



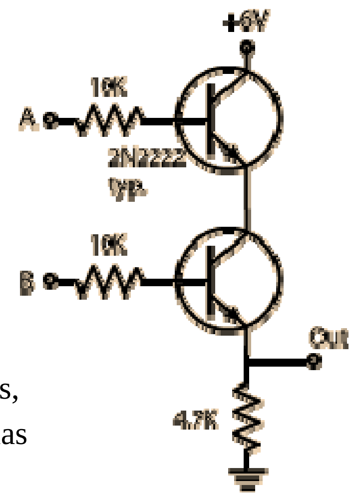
a) transistor descriptor

A textbook author describing a npn bipolar junction transistor writes:

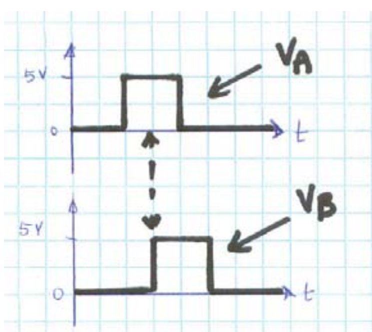
> *"the collector operates like a vacuum cleaner for electrons"*.

Why is this a good analogy? Suggest a couple of other household items that would make reasonable analogies to explain the operation of the base and emitter regions.

b) gate circuit



Using TTL logic (+5 V = 'high', 0 V = 'low'), what logical function is performed by the circuit shown, and why?

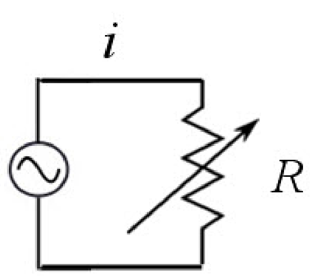


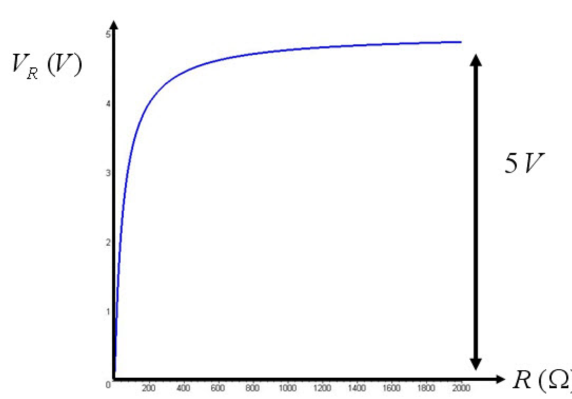
Voltage inputs V_A and V_B are applied to this circuit, as shown in the graph.

Sketch the output V_{out} as a function of t for these inputs, assuming that each BE junction turns on at a forward bias of 0.6 V.

c) Function generator problem?

A function generator is set to apply a sinewave voltage across a variable resistor R. Before being applied to the circuit, the amplitude of the function generator signal is measured as 5 V.





No adjustments are made to the function generator settings, and its output is then connected across the resistor R as shown.

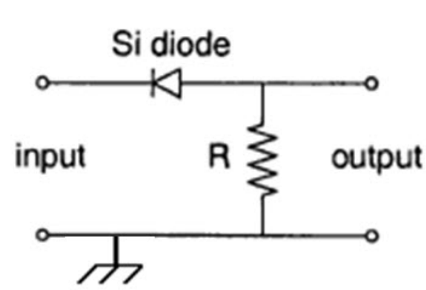
The amplitude of the voltage waveform across the variable resistor is then measured versus R, as shown in the figure.

The measured amplitude is 5 V for large R and starts to decrease significantly below $R \sim 200\ \Omega$. What, if anything, is wrong with the function generator? Explain briefly!

d) diode response

Sketch the I-V curve for a silicon diode ($V_t = 0.6$ V), noting any important features.

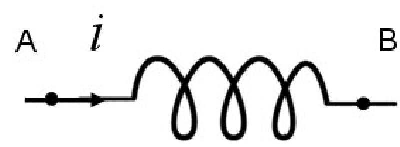
A silicon diode is connected in a circuit with a fixed resistor *R*. The input is a sinewave with amplitude 1.2 V.



Sketch the input and output waveforms versus time on the same graph for one AC cycle, taking care to label the vertical scale appropriately.

4. Magnetic Induction

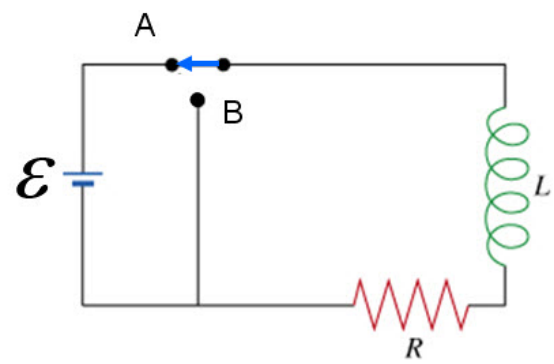
a) The circuit symbol for an ideal inductor with self-inductance L is shown in the diagram.



Show that the work done by an external agent to establish the current $i(t)$, and hence the magnetic potential energy stored in the inductor,

is given by $U(t) = \frac{1}{2} L\, i(t)^2$.

b) An inductor is connected in series with a resistor as shown. The switch is initially connected at point A for a long time (i.e. for $t < 0$), and then at $t = 0$ it is suddenly moved to point B.



Write down and solve an equation for the current $i(t)$ that flows in the circuit for $t > 0$.

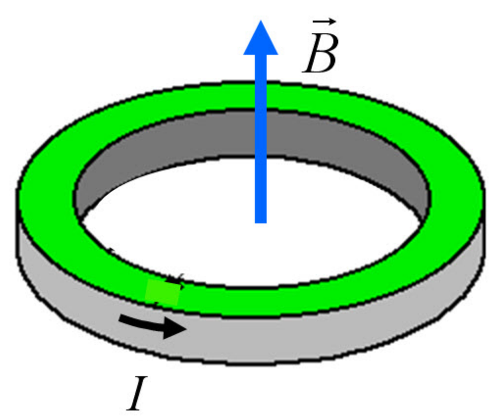
Sketch a graph of your solution for i versus t. What is the exponential decay time τ ?

c) A second coil of wire has self-inductance L' and is situated near the circuit of part b). There is a mutual inductance M between the two coils, where $M > 0$.

What time-varying EMF appears across the second coil for $t > 0$ and why? (Assume the 2nd coil is an open circuit.)

What factors determine the value of M ?

d) Consider a ring of current, I, with square cross-sectional area A and average radius r.



Assume that the current density is uniform inside the ring, and that the magnetic field is uniform and perpendicular to the plane of the ring as shown, with $B = \frac{\mu_o I}{2r}$.

The material of the ring has resistivity ρ.

Work out expressions for the self-inductance L and the resistance R of the ring in terms of the quantities given.

If the current is driven by a source of EMF (not shown) that is suddenly disconnected at $t = 0$, find an expression for the exponential decay time τ in terms of the quantities given.

Evaluate τ for the condition: $A = r^2$, $r = 3\times10^6$ m, $\rho = 10^{-6}\ \Omega\,\text{m}$, and express your answer in years.

→ Data: $\mu_o = 4\pi\times10^{-7}$ H/m, and 1 y $\approx \pi\times10^7$ s.

These figures give a rough estimate for the timescale to change the earth's magnetic field in response to a sudden change in its internal EMF (the details of which are still not completely understood!).

The End ☺