

~~We strongly recommend that you read about a topic before it is covered in lectures.~~

<del>Lecture Date</del>	<del>Topics Covered</del>	<del>Reading from Giancoli</del>
<del>#20 Mon 4/1</del>	<del>Inductance – RL Circuits Magnetic Field Energy</del>	<del>Chapter 30 through Sect. 30-4</del>
<del>Tue 4/2</del>	<del>Due Date Electric Motor! Testing 1-5 PM, 26-110</del>	
<del>#21 Wed 4/3</del>	<del>Magnetic Materials Dia-, Para-, and Ferromagnetism Prize Ceremony Motor Contest</del>	<del>Lecture Supplement Sect. 28-8, 28-9, 28-10</del>
<del>#22 Fri 4/5</del>	<del>Hysteresis – Electromagnets – Bohr Magneton Maxwell's Equations</del>	<del>Sect. 28-8 &amp; 28-9 Sect. 32-3 &amp; 40-7</del>

~~Due before 4 PM, Friday, April 5 in 4-339B.~~

~~Problem 6.1~~

~~Flip Coil.~~

~~Giancoli 29-62.~~

~~Problem 6.2~~

~~Displacement Current.~~

~~Giancoli 32-4.~~

~~Problem 6.3~~

~~Self-inductance of a toroid.~~

~~Giancoli 30-48.~~

~~Problem 6.4~~

~~Magnetic Field Energy and Self-Inductance.~~

~~A long straight solid cylindrical conducting wire with radius  $R$  carries a steady uniform current  $I$ .~~

- ~~(a) Calculate the magnetic field energy inside a length  $\ell$  of the wire.~~
- ~~(b) What is the contribution of the interior portion of the conductor to the total self-inductance?~~

~~Problem 6.5~~

~~RL Circuit.~~

~~A coil with resistance  $0.05 \Omega$  and self-inductance  $0.09 \text{ H}$  is connected across a 12-volt car battery of negligible internal resistance.~~

- ~~(a) How long after the switch is closed will the current reach 95 percent of its final value?~~
- ~~(b) At that time how much energy (in Joules) is stored in the magnetic field?~~
- ~~(c) How much energy has been delivered by the battery up to that time?~~

~~(b) From the relationship between stored magnetic field energy and self-inductance (Giancoli Equation (30-6), p. 761), we can identify the self-inductance due to the interior of the wire:~~

$$U_{\text{in}} = \frac{1}{2} L_{\text{in}} I^2 = \frac{\mu_0 I^2 \ell}{16\pi} \implies L_{\text{in}} = \frac{\mu_0 \ell}{8\pi} .$$

~~The wire therefore has a self-inductance per unit length  $\mu_0/8\pi$  associated with its internal magnetic field.~~

## Problem 6.5

*RL circuit.*

Giancoli Equation (30-9) (p. 762) gives us an expression for the time-dependent current in an  $LR$  circuit connected to a battery of voltage  $V_0$  at time  $t = 0$ :

$$I(t) = \frac{V_0}{R} (1 - e^{-t/\tau}) , \quad \tau = L/R .$$

We will make good use of this! For our circuit, the time constant is  $\tau = (0.09)/(0.05) = 1.8$  s.

(a) The final value of the current is simply  $V_0/R$ . Let  $\alpha = 0.95$ ; the condition that the current has reached 95% of its final value can then be expressed as

$$\begin{aligned} I &= \frac{V_0}{R} (1 - e^{-t/\tau}) = (1 - \alpha) \frac{V_0}{R} \\ \Rightarrow e^{-t/\tau} &= \alpha \\ \Rightarrow t &= -\tau \ln \alpha = 5.4 \text{ s} . \end{aligned}$$

(b) Using Giancoli Equation (30-6) (p. 761), we have for the energy stored in the magnetic field

$$U = \frac{1}{2} L I^2 = \frac{1}{2} L (1 - \alpha)^2 \frac{V_0^2}{R^2} = \frac{1}{2} (0.09) (0.95)^2 \frac{(12)^2}{(0.05)^2} \simeq 2300 \text{ J} .$$

(c) The power delivered by the battery at any instant is

$$P(t) = V_0 I(t) = \frac{V_0^2}{R} (1 - e^{-t/\tau}) .$$

To find the total energy  $W$  delivered by the battery up to the time  $t$  found in part (a) we integrate:

$$\begin{aligned} W &= \int_0^t P(t') dt' = \frac{V_0^2}{R} \int_0^t (1 - e^{-t'/\tau}) dt' = \frac{V_0^2}{R} [t' + \tau e^{-t'/\tau}]_0^t \\ &= \frac{V_0^2}{R} [t - (1 - \alpha)\tau] = \frac{(12)^2}{(0.05)^2} [5.4 - (0.95)(1.8)] \simeq 10600 \text{ J} . \end{aligned}$$

So,  $\simeq 10600 - 2300 = 8300$  J have been dissipated in the resistor.

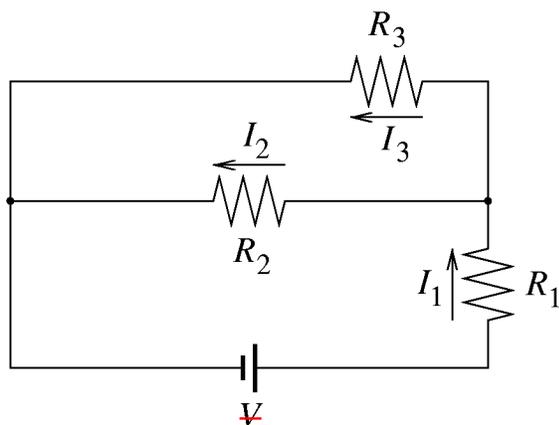
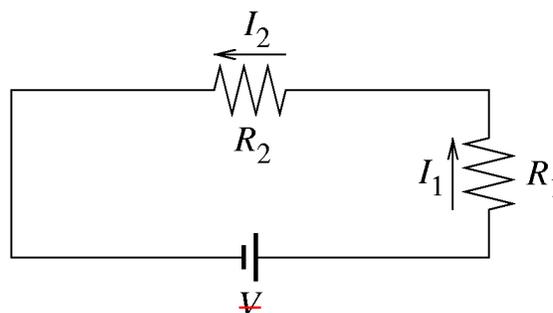
### ~~Problem 6.6~~

~~RL circuit. (Ciancoli 30-30.)~~

~~The inductor in the upper branch of the circuit will resist instantaneous changes in  $I_3$ . Negligible inductance in the rest of the circuit means that  $I_1$  and  $I_2$  can respond essentially instantaneously to the opening and closing of the switch. (Note: these solutions use  $V$  instead of  $\mathcal{E}$  to denote the battery voltage.)~~

~~(a) Before the switch is closed, all currents are zero. Immediately after the switch is closed,  $I_3 = 0$  still. At this instant, we may regard the circuit effectively as shown at right. This situation solves easily to give~~

$$I_1 = I_2 = \frac{V}{R_1 + R_2} .$$



~~(b) After the switch has been closed for a long time, all the currents will have reached unchanging, steady-state values. Inductors have no effect when currents are not changing in time, so we may treat the circuit as shown at left. Applying Kirchoff's rules we obtain~~

$$I_1 = I_2 + I_3 , \quad I_1 R_1 + I_2 R_2 = I_1 R_1 + I_3 R_3 = V .$$

~~A bit of algebra then yields~~

$$I_1 = V \left( R_1 + \frac{R_2 R_3}{R_2 + R_3} \right)^{-1} , \quad I_2 = V \left( R_1 + R_2 + \frac{R_1 R_2}{R_3} \right)^{-1} , \quad I_3 = V \left( R_1 + R_3 + \frac{R_1 R_3}{R_2} \right)^{-1} .$$

~~(c) Immediately after the switch is opened again, the branch containing the battery and  $R_1$  is taken out of action, so  $I_1 = 0$ . The remaining circuit is as shown at right.  $I_3$  must be continuous in time due to the inductor, so it has the same value as found in part (b). Kirchoff's loop rule (a.k.a. charge conservation) then dictates  $I_2 = -I_3$ .~~

