PHYS 1444 – Section 004
Lecture #20

Monday, April 16, 2012
Dr. Jaehoon Yu

- Inductor
- Energy Stored in a Magnetic Field
- LR circuit
- AC Circuit w/ Resistance only
- AC Circuit w/ Inductance only
- AC Circuit w/ Capacitance only

Today's homework is #12, due 10pm, Tuesday, Apr. 24!!

Announcements

- Your planetarium extra credit
  - Please bring your planetarium extra credit sheet by the beginning of the class next Monday, Apr. 30
  - Be sure to tape one edge of the ticket stub with the title of the show on top
  - Be sure to write your name onto the sheet
- Term exam #2
  - Non-comprehensive
  - Date and time: 5:30 – 6:50pm, Wednesday, Apr. 25
  - Location: SH103
  - Coverage: CH. 27 – 1 to what we finish Monday, Apr. 23
  - Please do NOT miss the exam!!
- Reading Assignments
  - CH30.9 – CH30.11
- Colloquium this week
  - Dr. Jean Gao of UTA

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Analysis of Serum Proteomic Profiles for Biomarker Identification and Sample Prediction

Dr. Jean Gao

University of Texas at Arlington
Computer Science and Engineering Department

4:00 pm Wednesday April 18, 2012 room 101 SH

Abstract:

Biomarkers measured in minimally invasive and repeatable ways can expedite the early diagnosis of disease, the measurement of therapeutic toxicity, the indication of disease prognosis, and the discovery of new drug targets for therapy. Traditional serum proteomic profilings mainly use low resolution mass spectrometry to identify high-mass protein products. However, the low-molecular weight (LMW) end of the spectrum--that tends to contain more biomarkers--is missed. High resolution mass spectrometry is required to analyze rich LMW biomarkers.

In this talk, I will present high-resolution MS data analysis methods for multi-class proteomic biomarker selection and classification. These analysis methods use high-resolution input data which are superior to low-resolution spectra in terms of both sensitivity and specificity. A multi-class classifier ensemble will be presented first for sample prediction. A subspace feature (biomarker, mass/charge ratio) selection algorithm using a wrapper framework will then be shown to handle the data high-dimensionality. Unique biomarker patterns will be found differentiating different phenotypes. Finally, a two-way parallel searching method will be described for the sequencing of biomarkers. I will conclude the talk with an overview of my other projects including protein microarray for signaling pathway inference, medical imaging for sub-cellular structure mobility study, system biology modeling of biomaterial-mediated foreign body responses, and an assistive intelligent device for blind and visually impaired people.

Refreshments will be served at 3:30p.m in the Physics Library

Special Project #5

- **B due to current I in a straight wire.** For the field near a long straight wire carrying a current I, show that

(a) The Ampere's law gives the same result as the simple long straight wire, $B=\mu_0 I/2\pi R$. (10 points)

(b) That Biot-Savarat law gives the same result as the simple long straight wire, $B=\mu_0 I/2\pi R$. (10 points)

- Must be your OWN work. No credit will be given for for copying straight out of the book, lecture notes or from your friends' work.
- Due is at the beginning of the class this Wednesday, Apr. 18.

Inductor

- An electrical circuit always contains some inductance but is normally negligibly small
  - If a circuit contains a coil of many turns, it could have large inductance
- A coil that has significant inductance, $\mathcal{L}$, is called an inductor and is express with the symbol 
  - Precision resisters are normally wire wound
    - Would have both resistance and inductance
    - The inductance can be minimized by winding the wire back on itself in opposite direction to cancel magnetic flux
    - This is called a "non-inductive winding"
- If an inductor has negligible resistance, inductance controls the changing current
- For an AC current, the greater the inductance the less the AC current
  - An inductor thus acts like a resistor to impede the flow of alternating current (not to DC, though. Why?)
  - The quality of an inductor is indicated by the term **reactance** or **impedance**

Example 30 – 3

Solenoid inductance. (a) Determine the formula for the self inductance $\mathcal{L}$ of a tightly wrapped solenoid (a long coil) containing N turns of wire in its length ℓ and whose cross-sectional area is A. (b) Calculate the value of $\mathcal{L}$ if N=100, ℓ=5.0cm, A=0.30cm^2 and the solenoid is air filled. (c) calculate $\mathcal{L}$ if the solenoid has an iron core with $\mu=4000\mu_0$.

What is the magnetic field inside a solenoid? $B=\mu_0 nI=\mu_0 NI/l$

The flux is, therefore, $\Phi_B=BA=\mu_0 NIA/l$

Using the formula for self inductance: $L=\dfrac{N\Phi_B}{I}=\dfrac{N\cdot\mu_0 NIA/l}{I}=\dfrac{\mu_0 N^2 A}{l}$

(b) Using the formula above

$$L=\frac{\mu_0 N^2 A}{l}=\frac{\left(4\pi\times10^{-7}\,T\cdot m/A\right)100^2\left(0.30\times10^{-4}\,m^2\right)}{5.0\times10^{-2}\,m}=7.5\mu H$$

(c) The magnetic field with an iron core solenoid is $B=\mu NI/l$

$$L=\frac{\mu N^2 A}{l}=\frac{4000\left(4\pi\times10^{-7}\,T\cdot m/A\right)100^2\left(0.30\times10^{-4}\,m^2\right)}{5.0\times10^{-2}\,m}=0.030H=30mH$$

Energy Stored in the Magnetic Field

- When an inductor of inductance L is carrying current I which is changing at a rate dI/dt, energy is supplied to the inductor at a rate
  - $P = I\varepsilon = IL\frac{dI}{dt}$
- What is the work needed to increase the current in an inductor from 0 to I?
  - The work, dW, done in time dt is $dW = Pdt = LI\,dI$
  - Thus the total work needed to bring the current from 0 to I in an inductor is

$$W = \int dW = \int_0^I LI\,dI = L\left[\frac{1}{2}I^2\right]_0^I = \frac{1}{2}LI^2$$

Energy Stored in the Magnetic Field

- The work done to the system is the same as the energy stored in the inductor when it is carrying current I
  - $$\boxed{U = \frac{1}{2}LI^2}$$ **Energy Stored in a magnetic field inside an inductor**
  - This is compared to the energy stored in a capacitor, C, when the potential difference across it is V: $U = \frac{1}{2}CV^2$
  - Just like the energy stored in a capacitor is considered to reside in the electric field between its plates
  - The energy in an inductor can be considered to be stored in its magnetic field

Stored Energy in terms of B

- So how is the stored energy written in terms of magnetic field B?
  - Inductance of an ideal solenoid without a fringe effect

    $$L = \mu_0 N^2 A/l$$

  - The magnetic field in a solenoid is $B = \mu_0 NI/l$
  - Thus the energy stored in an inductor is

    $$U = \frac{1}{2}LI^2 = \frac{1}{2}\frac{\mu_0 N^2 A}{l}\left(\frac{Bl}{\mu_0 N}\right)^2 = \frac{1}{2}\frac{B^2}{\mu_0}Al$$

  - Thus the energy density is

    $$u = \frac{U}{V} = \frac{U}{Al} = \frac{1}{2}\frac{B^2}{\mu_0}$$

  - This formula is valid in any region of space
  - If a ferromagnetic material is present, μ_0 becomes μ.

What is this?

Volume V

$$\boxed{U = \frac{1}{2}\frac{B^2}{\mu_0}Al}$$ **E**

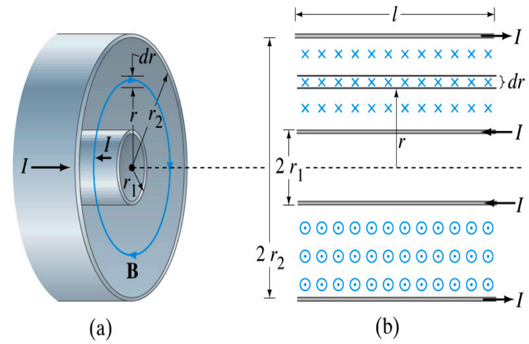
$$\boxed{u = \frac{1}{2}\frac{B^2}{\mu_0}}$$ **E density**

What volume does Al represent?

The volume inside a solenoid!!

Example 30 – 5

Energy stored in a coaxial cable. (a) How much energy is being stored per unit length in a coaxial cable whose conductors have radii r_1 and r_2 and which carry a current I? (b) Where is the energy density highest?



(a) The total flux through l of the cable is $\Phi_B = \int Bl\,dr = \frac{\mu_0 Il}{2\pi}\int_{r_1}^{r_2}\frac{dr}{r} = \frac{\mu_0 Il}{2\pi}\ln\frac{r_2}{r_1}$

Thus inductance per unit length for a coaxial cable is $\frac{L}{l} = \frac{\mu_0}{2\pi}\ln\frac{r_2}{r_1}$

Thus the energy stored per unit length is $\frac{U}{l} = \frac{1}{2}\frac{LI^2}{l} = \frac{\mu_0 I^2}{4\pi}\ln\frac{r_2}{r_1}$

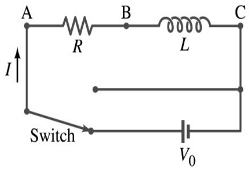
(b) Since the magnetic field is $B = \frac{\mu_0 I}{2\pi r}$

And the energy density is $u = \frac{1}{2}\frac{B^2}{\mu_0}$

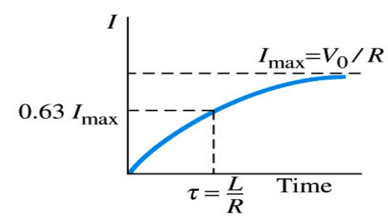
The energy density is highest where B is highest. Since B is highest close to $r=r_1$, near the surface of the inner conductor.

LR Circuits

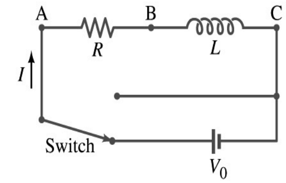
- What happens when an emf is applied to an inductor?
  - An inductor has some resistance, however negligible



    - So an inductor can be drawn as a circuit of separate resistance and coil. What is the name this kind of circuit? **LR Circuit**
  - What happens at the instance the switch is thrown to apply emf to the circuit?
    - The current starts to flow, gradually increasing from 0
    - This change is opposed by the induced emf in the inductor ➔ the emf at point B is higher than point C
    - However there is a voltage drop at the resistance which reduces the voltage across inductance
    - Thus the current increases less rapidly
    - The overall behavior of the current is a gradual increase, reaching to the maximum current $I_{max}=V_0/R$.

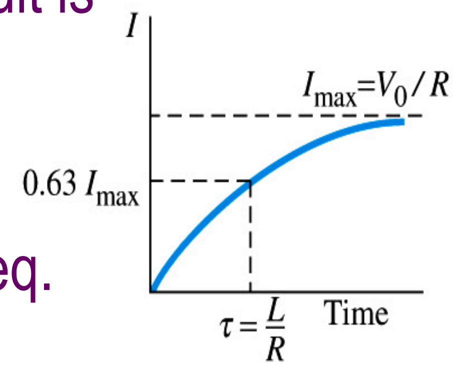


LR Circuits



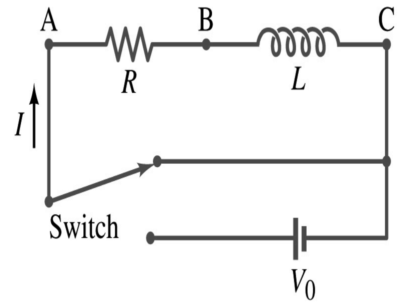
- This can be shown w/ Kirchhoff loop rules
  - The emfs in the circuit are the battery voltage V_0 and the emf $\varepsilon=-\mathcal{L}(d\mathcal{I}/dt)$ in the inductor opposing the current increase
  - The sum of the potential changes through the circuit is

$$V_0 + \varepsilon - IR = V_0 - L\,dI/dt - IR = 0$$

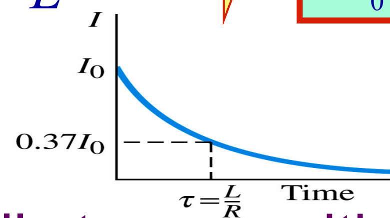


  - Where $\mathcal{I}$ is the current at any instance
  - By rearranging the terms, we obtain a differential eq.
  - $L\,dI/dt + IR = V_0$
  - We can integrate just as in RC circuit $\int_{I=0}^{I} \frac{dI}{V_0 - IR} = \int_{t=0}^{t} \frac{dt}{L}$
  - So the solution is $-\frac{1}{R}\ln\left(\frac{V_0 - IR}{V_0}\right) = \frac{t}{L}$ $\boxed{I = V_0\left(1-e^{-t/\tau}\right)/R = I_{max}\left(1-e^{-t/\tau}\right)}$
  - Where τ=L/R
    - This is the time constant τ of the LR circuit and is the time required for the current $\mathcal{I}$ to reach 0.63 of the maximum

Discharge of LR Circuits

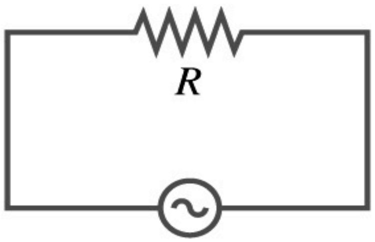


- If the switch is flipped away from the battery
  - The differential equation becomes
  - $L\,dI/dt + IR = 0$
  - So the integration is $\int_{I_0}^{I} \frac{dI}{IR} = \int_{t=0}^{t} \frac{dt}{L}$ $\boxed{\ln\frac{I}{I_0} = -\frac{R}{L}t}$
  - Which results in the solution
  - $\boxed{I = I_0 e^{-\frac{R}{L}t} = I_0 e^{-t/\tau}}$



  - The current decays exponentially to zero with the time constant τ=L/R
  - So there always is a reaction time when a system with a coil, such as an electromagnet, is turned on or off.
  - The current in LR circuit behaves almost the same as that in RC circuit but the time constant is inversely proportional to R in LR circuit unlike the RC circuit

AC Circuit w/ Resistance only



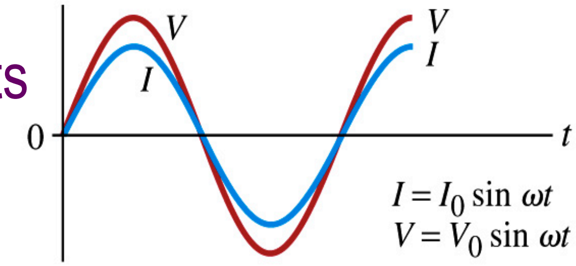
- What do you think will happen when an AC source is connected to a resistor?
- From Kirchhoff's loop rule, we obtain

$$V - IR = 0$$

- Thus

$$V = I_0 R \sin \varpi t = V_0 \sin \varpi t$$

  – where $V_0 = I_0 R$
- What does this mean?
  – Current is 0 when voltage is 0 and current is in its peak when voltage is in its peak.
  – Current and voltage are "in phase"



- Energy is lost via the transformation into heat at an average rate $\overline{P} = \overline{I}\,\overline{V} = I_{rms}^2 R = V_{rms}^2 / R$