PHYS 1444 – Section 003
Lecture #21

Tuesday, Nov. 15, 2011

Dr. Jaehoon Yu

- Electric Generators
- DC Generator
- Eddy Currents
- Transformer
- Generalized Faraday's Law
- Inductance

Today's homework is #11, due 10pm, Sunday, Nov. 20!!

Announcements

- Quiz results
  - Class average: 46.5/80
    - Equivalent to 58.1/100
    - Previous results: 45.6/100 and 65.7/100
  - Top score: 80/80
- Term exam #2
  - Date and time: 12:30 – 2:00pm, Tuesday, Nov. 22
  - Location: SH103
  - Coverage: CH. 26 – 3 to what we finish today
  - A review session on Thursday, Nov. 17, in SH103
  - Please do NOT miss the exam!!
- Reading assignments
  - CH29 – 5 and CH29 – 8
- Colloquium this week
  - Dr. John Turner

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Hydrogen Production from Photoelectrochemical Cells: Theoretical considerations and experimental results

Dr. John A. Turner
National Renewable Energy Laboratory
Golden, Colorado

4:00p.m Thursday November 17, 2011
Room 101 Science Hall

Abstract:

To date, no semiconducting material has been discovered that simultaneously meets all the criteria required for economical hydrogen production via light-driven direct water splitting. Considerable work has been directed at metal oxides due to their expected stability and low costs, unfortunately after 35 years of work little progress has been made, efficiencies for these oxides remains very low. For a viable material, semiconductors for photoelectrochemical water splitting must have the same fundamental internal quantum efficiency as the commercial high efficiency PV devices. Multi-component transition metal oxides are complex materials, making intuitive guesses impossible and a focused search very challenging. So to achieve suitable photo-electrode materials, the electronic properties of the materials and their response to defect formation must be understood. A computational approach may be the only approach that can give us the necessary insight into these mixed metal oxides and allow us to narrow the composition space leading us towards a successful material.

The highest efficiency PV devices are III-V material based and likewise the highest efficiency PEC water splitting devices are III-V based. This report will discuss issues relating to metal oxides and summarize our efforts on III-V materials and their application to tandem cells for photoelectrochemical water splitting.

Refreshments will be served at 3:30p.m in the physics lounge

Reminder: Special Project #6

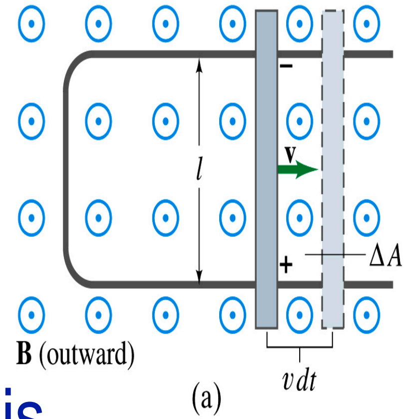
B due to current I in a straight wire. For the field near a long straight wire carrying a current I, show that

(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 or from your friend's work.
- Due is at the beginning of the exam on Tuesday, Nov. 22.

EMF Induced on a Moving Conductor



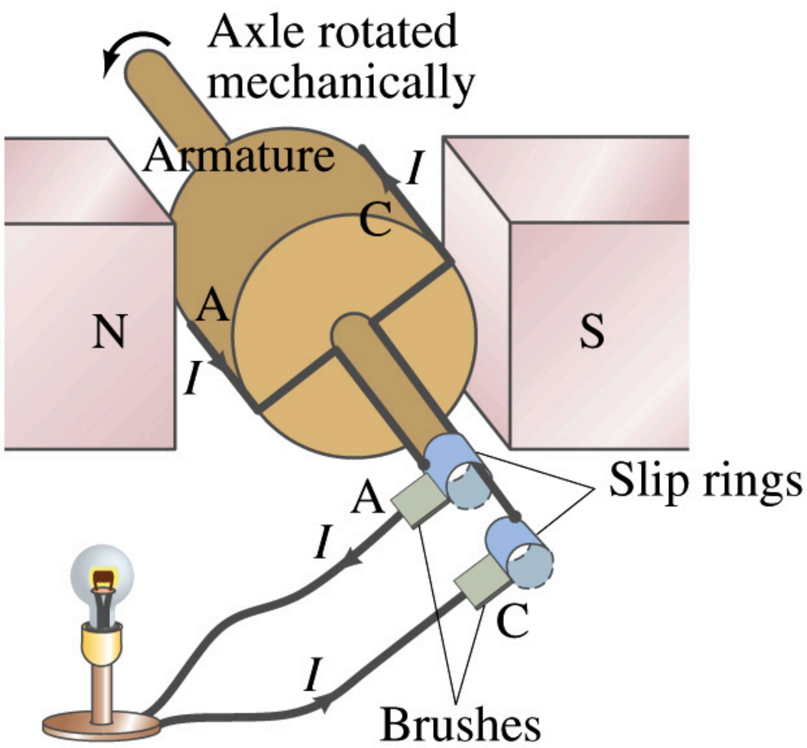
- Another way of inducing emf is using a U shaped conductor with a movable rod resting on it.
- As the rod moves at a speed v, it travels $v$dt in time dt, changing the area of the loop by dA=lvdt.
- Using Faraday's law, the induced emf for this loop is

$$|\varepsilon| = \frac{d\Phi_B}{dt} = \frac{BdA}{dt} = \frac{Blvdt}{dt} = Blv$$

  - This equation is valid as long as B, l and v are perpendicular to each other. What do we do if not?
    - Use the scalar product of vector quantities
- An emf induced on a conductor moving in a magnetic field is called a **motional emf**

Electric Generators

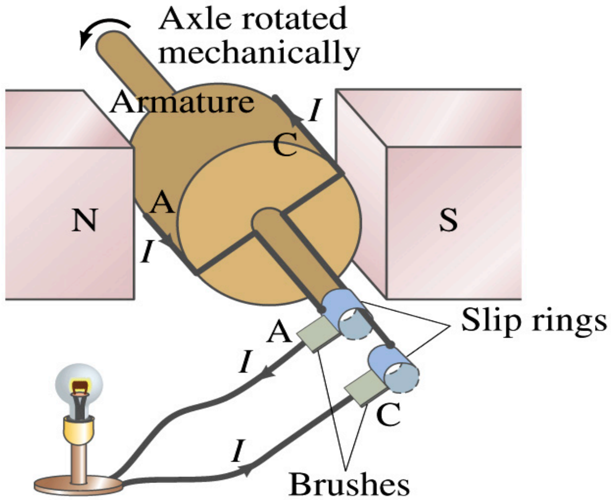
- What does a generator do?
  - Transforms mechanical energy into the electrical energy
  - What does this look like?
    - An inverse of an electric motor which transforms electrical energy to mechanical energy
  - An electric generator is also called a dynamo



- Whose law does the generator based on?
  - Faraday's law of induction

How does an Electric Generator work?

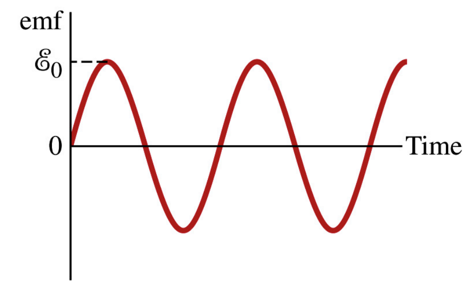
- An electric generator consists of
  - Many coils of wires wound on an armature that can rotate by mechanical means in a magnetic field
- An emf is induced in the rotating coil
- Electric current is the output of a generator



- Which direction does the output current flow when the armature rotates counterclockwise?
  - The conventional current flows outward on wire A toward the brush
  - After half the revolution the wire A will be where the wire C is and the current flow on A is reversed
- Thus the current produced is alternating its direction

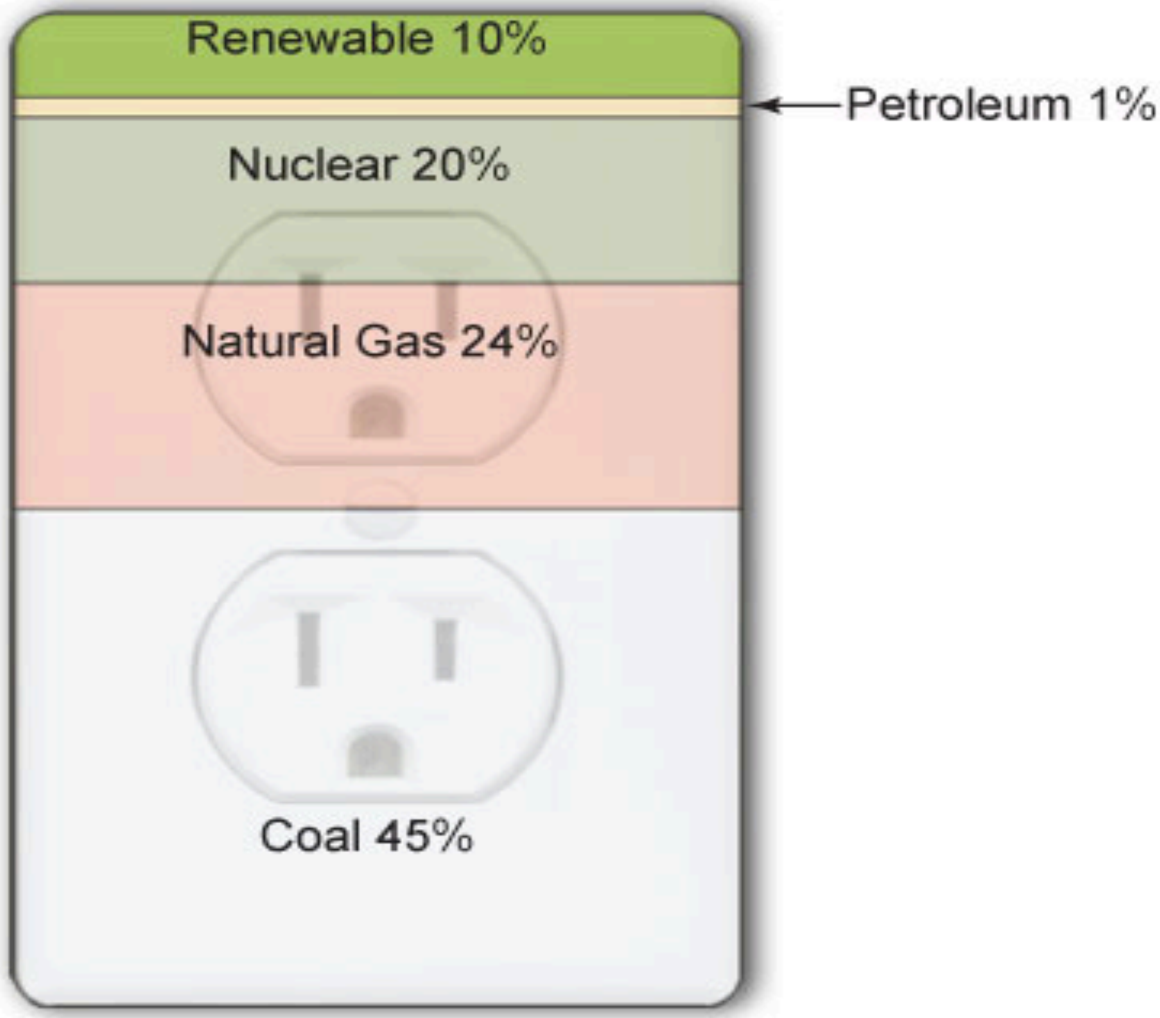
How does an Electric Generator work?

- Let's assume the loop is rotating in a uniform B field w/ a constant angular velocity ω. The induced emf is
- $\varepsilon = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A} = -\frac{d}{dt}[BA\cos\theta]$
- What is the variable that changes above?
  - The angle θ. What is dθ/dt?
    - The angular speed ω.
  - So $\theta=\theta_0+\omega t$
  - If we choose $\theta_0=0$, we obtain
  - $\varepsilon = -BA\frac{d}{dt}[\cos\varpi t] = BA\varpi\sin\varpi t$
  - If the coil contains N loops: $\varepsilon = -N\frac{d\Phi_B}{dt} = NBA\varpi\sin\varpi t = \varepsilon_0\sin\varpi t$
  - What is the shape of the output?
    - Sinusoidal w/ amplitude $\varepsilon_0=NBA\omega$



- US A frequency is 60Hz. Europe is at 50Hz
  - Most the U.S. power is generated at steam plants

Sources of U.S. Electricity Generation, 2010



Source: U.S. Energy Information Administration, *Monthly Energy Review* (June 2011). Percentages based on Table 7.2a, preliminary 2010 data.

The World Energy Consumption

- In 2008, total worldwide energy consumption was 474 EJ (474×10^{18} J=132,000 TWh).
  - Equivalent to an average energy consumption rate of 15 terawatts (1.504×10^{13} W)
- The potential for renewable energy
  - solar energy 1600 EJ (444,000 TWh)
  - wind power 600 EJ (167,000 TWh)
  - geothermal energy 500 EJ (139,000 TWh),
  - biomass 250 EJ (70,000 TWh)
  - hydropower 50 EJ (14,000 TWh) an
  - ocean energy 1 EJ (280 TWh)

Example 29 – 9

An AC generator. The armature of a 60-Hz AC generator rotates in a 0.15-T magnetic field. If the area of the coil is $2.0\text{x}10^{-2}\text{m}^2$, how many loops must the coil contain if the peak output is to be ε_0=170V?

The maximum emf of a generator is $\varepsilon_0 = NBA\varpi$

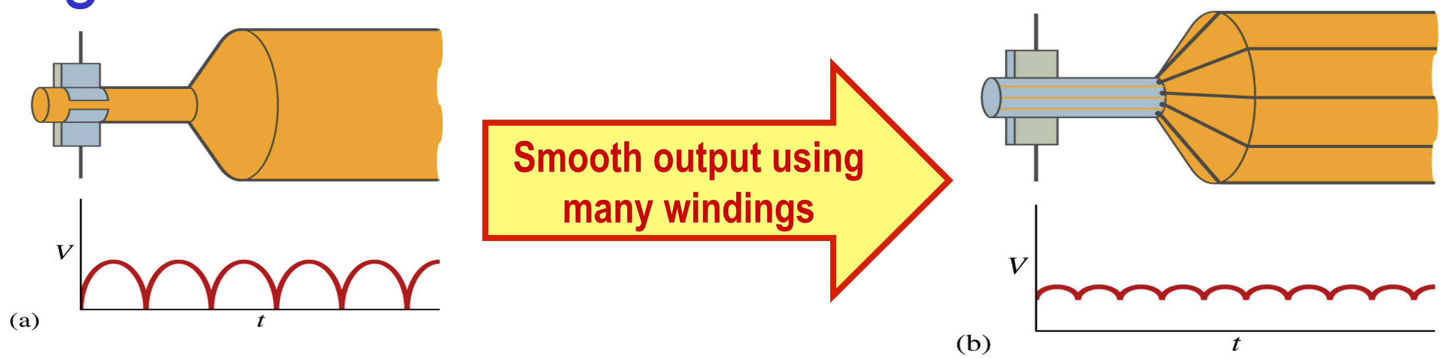
Solving for N $$N = \frac{\varepsilon_0}{BA\varpi}$$

Since $\varpi = 2\pi f$ We obtain

$$N = \frac{\varepsilon_0}{2\pi BAf} = \frac{170V}{2\pi \cdot (0.15T) \cdot \left(2.0\times 10^{-2} m^2\right) \cdot \left(60s^{-1}\right)} = 150 turns$$

A DC Generator

- A DC generator is almost the same as an AC generator except the slip rings are replaced by split-ring commutators



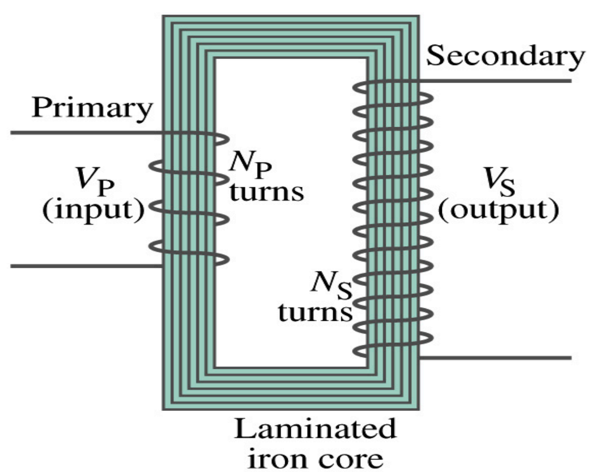
- Output can be smoothed out by placing a capacitor on the output
  – More commonly done using many armature windings

Eddy Currents (read more in 29-5)

- Induced currents are not always confined to well-defined path
- In some cases where a conductor is moving in and out of the magnetic field, the Lenz's law causes flow of electrons that opposes the change in magnetic flux
  - This change is in the direction that impedes the production of emf
  - And thus causes energy losses
- These currents are called eddy currents
  - Just like the eddy currents in the water that pulls the boat in the opposite direction of the movement

Transformer

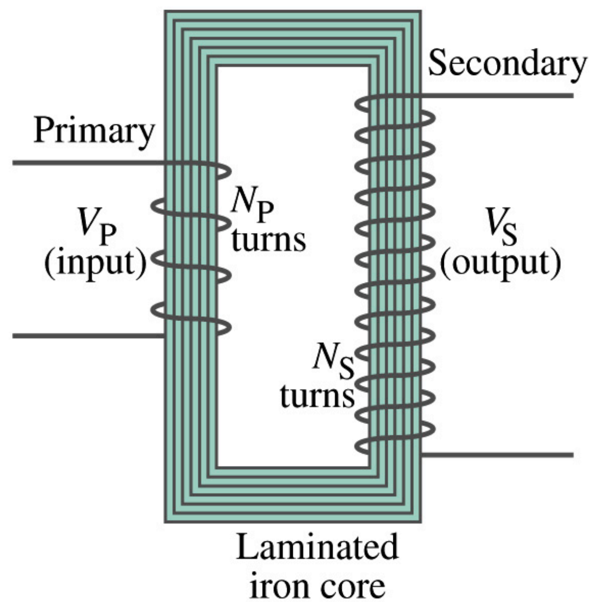
- What is a transformer?
  - A device for increasing or decreasing an AC voltage
  - A few examples?
    - TV sets to provide High Voltage to picture tubes, portable electronic device converters, transformers on the pole, etc
- A transformer consists of two coils of wires known as the primary and the secondary
  - The two coils can be interwoven or linked by a laminated soft iron core to reduce eddy current losses
- Transformers are designed so that all magnetic flux produced by the primary coil pass through the secondary



How does a transformer work?

- When an AC voltage is applied to the primary, the changing B it produces will induce voltage of the same frequency in the secondary wire
- So how would we make the voltage different?
  - By varying the number of loops in each coil
  - From Faraday's law, the induced emf in the secondary is
  - $V_S = N_S \frac{d\Phi_B}{dt}$
  - The input primary voltage is
  - $V_P = N_P \frac{d\Phi_B}{dt}$
  - Since $d\Phi_B/dt$ is the same, we obtain
  - $\frac{V_S}{V_P} = \frac{N_S}{N_P}$

Transformer Equation



Transformer Equation

- The transformer equation does not work for DC current since there is no change of magnetic flux!!
- If $N_S>N_P$, the output voltage is greater than the input so it is called a step-up transformer while $N_S<N_P$ is called step-down transformer
- Now, it looks like energy conservation is violated since we can get more emf from smaller ones, right?
  - Wrong! Wrong! Wrong! Energy is always conserved!
  - A well designed transformer can be more than 99% efficient
  - The power output is the same as the input:
  - $V_P I_P = V_S I_S$
  - $$\frac{I_S}{I_P} = \frac{V_P}{V_S} = \frac{N_P}{N_S}$$

The output current for step-up transformer will be lower than the input, while it is larger for step-down x-former than the input.

Example for A Transformer

Portable radio transformer. A transformer for home use of a portable radio reduces 120-V AC to 9.0V AC. The secondary contains 30 turns, and the radio draws 400mA. Calculate (a) the number of turns in the primary (b) the current in the primary and (c) the power transformed.

(a) What kind of a transformer is this? A step-down x-former

Since $\frac{V_P}{V_S} = \frac{N_P}{N_S}$ We obtain $N_P = N_S \frac{V_P}{V_S} = 30 \frac{120V}{9V} = 400 turns$

(b) Also from the transformer equation $\frac{I_S}{I_P} = \frac{V_P}{V_S}$ We obtain $I_P = I_S \frac{V_S}{V_P} = 0.4A \frac{9V}{120V} = 0.03A$

(c) Thus the power transformed is

$$P = I_S V_S = (0.4A) \cdot (9V) = 3.6W$$

How about the input power? The same assuming 100% efficiency.

Example 29 – 13: Power Transmission

Transmission lines. An average of 120kW of electric power is sent to a small town from a power plant 10km away. The transmission lines have a total resistance of 0.4Ω. Calculate the power loss if the power is transmitted at (a) 240V and (b) 24,000V.

We cannot use $P=V^2/R$ since we do not know the voltage along the transmission line. We, however, can use $P=I^2R$.

(a) If 120kW is sent at 240V, the total current is

$$I=\frac{P}{V}=\frac{120\times10^3}{240}=500A.$$

Thus the power loss due to transmission line is

$$P=I^2R=(500A)^2\cdot(0.4\Omega)=100kW$$

(b) If 120kW is sent at 24,000V, the total current is

$$I=\frac{P}{V}=\frac{120\times10^3}{24\times10^3}=5.0A.$$

Thus the power loss due to transmission line is

$$P=I^2R=(5A)^2\cdot(0.4\Omega)=10W$$

The higher the transmission voltage, the smaller the current, causing less loss of energy. This is why power is transmitted w/ HV, as high as 170kV.

Electric Field due to Magnetic Flux Change

- When electric current flows through a wire, there is an electric field in the wire that moves electrons
- We saw, however, that changing magnetic flux induces a current in the wire. What does this mean?
  - There must be an electric field induced by the changing magnetic flux.
- In other words, a changing magnetic flux produces an electric field
- This results apply not just to wires but to any conductor or any region in space

Generalized Form of Faraday's Law

- Recall the relationship between the electric field and the potential difference $V_{ab} = \int_a^b \vec{E} \cdot d\vec{l}$
- Induced emf in a circuit is equal to the work done per unit charge by the electric field
- $\varepsilon = \oint \vec{E} \cdot d\vec{l}$
- So we obtain

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

- The integral is taken around a path enclosing the area through which the magnetic flux Φ_B is changing.