Electronics - PHYS 2371/2

Welcome to

Electronics for Scientists

PHYS 2371/2372

← Don Heiman

Hari Kumarakuru →

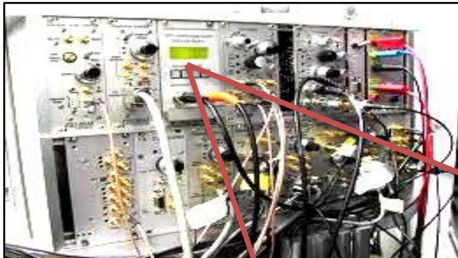
Topics Today

(1) Course structure

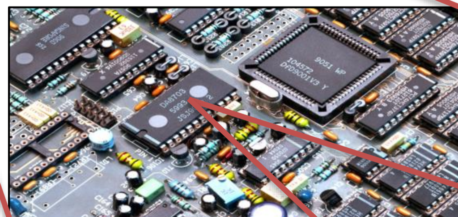
(2) Introduction/Background

(3) Electronics basics

(4) First lab experiment

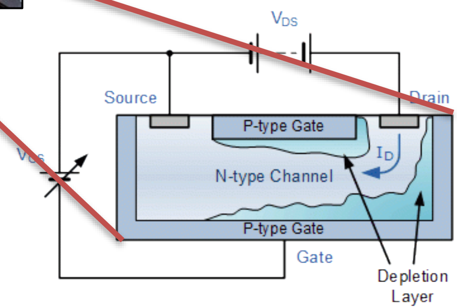


← Large-scale electronics

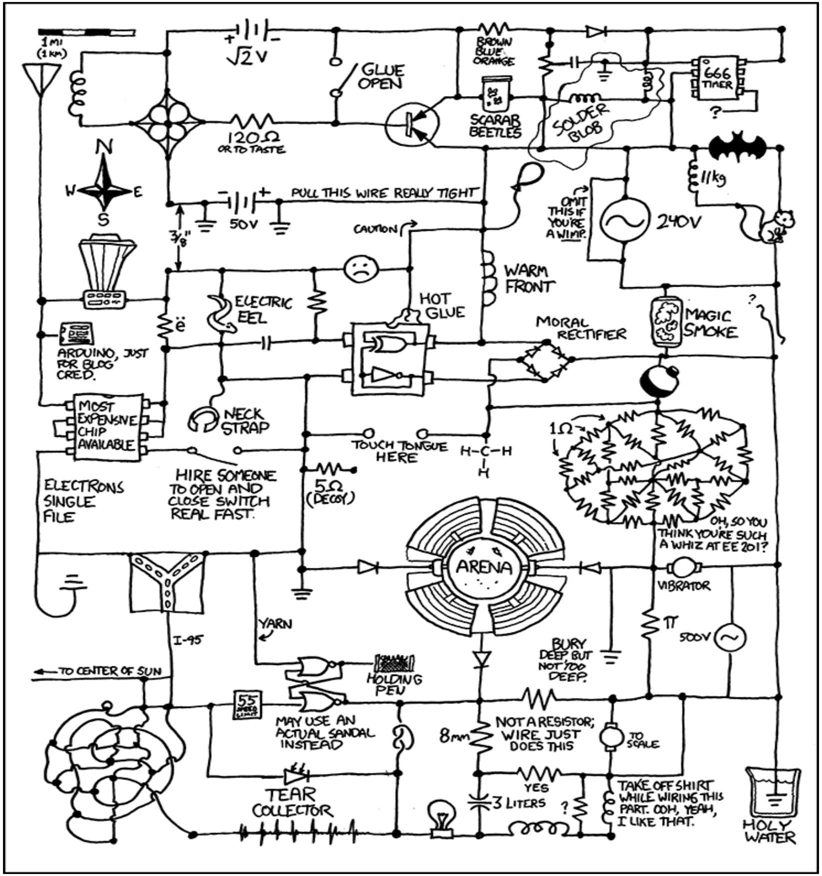


← Integrated circuits

Discrete devices
FET →



Electronics - PHYS 2371/2



A typical circuit

or

An atypical circuit

from xkcd.com

Electronics - PHYS 2371/2

Electronics is ubiquitous in our lives and we could hardly function without it. This is a stimulating course that will give you some background on the underlying physics of electronics, as well as a survey of some of the latest technology.

Electronics - PHYS 2371/2

Topics Today

(1) Course structure

(2) Introduction/Background

(3) Electronics basics

(4) First lab experiment

All of the material for the course can be accessed via the Calendar website or from Canvas.

It shows a list of items for each week of the course, including the topics covered, homework assignments and the lab experiments to be performed.

It contains links to the Lectures, Homework Assignments and Lab Instructions.

It also has links to the Syllabus and Course Description.

Electronics - PHYS 2371/2

web.northeastern.edu/heiman/237

https://web.northeastern.edu/heim

Search

NU mail | Physics | Scholar | Wiki | PHYS 2371 | myNEU | Scholar NU | Reopening

Calendar of Topics Covered

Physics PHYS 2371/2372, Electronics for Scientists

Don Heiman and Hari Kumarakuru

Northeastern University, Fall 2020

Also see **Course Description** and **Syllabus**

This is a schedule of the topics covered, but it may be modified occasionally (08/11/2020).

Week #	Lectures	Weekly Topics (Chs.)	Homework (Ch-Problem)	Lab Experiments (always look for latest version)
I Sept 9-11	Wed Lecture Introduction	Basic Concepts (Ch-2) Ch-16, Digital Multimeters		*Worksheet-1, Electronics Introduction* (multimeter, voltage sources)
II Sept 16-18	Wed Lecture Electronic Basics	Basic Circuit Analysis (Ch-3) Some Simple Circuits (Ch-4) Resistor/ Capacitor (Ch-47/48)	2-8/9, 3-5/6, 4-4/8, 4-13/14	*Worksheet-2, Electronic Basics*
III Sept 23-25	Wed Lecture Time-Dependent AC Circuits	The Oscilloscope (Ch-17) AC and Elements of Circuits (Ch-7/8) Circuit Analysis (LRC) (Ch-9/12) Resonance (Ch-10)	7-all, 8-3 12-all	*Worksheet-3, Time-Dependent AC Circuits* (R, RC, LRC)
IV Sept 30-Oct 2	Wed Lecture Semiconductor Devices	Solid State Devices (Ch-40) *p-n* Junction Diodes (Ch-41) Transistors/Circuits (Ch-42-45)	HW Handout	*Worksheet-4, Say Hello (and Goodbye) to the Transistor*
V Oct 7-9	Wed Lecture Operational Amplifiers	Op-Amp Basics (Ch-28, 31) Basic Op-Amp Circuits (Ch-29)	28-1/3/4, 29-1/2/3/4	*Lab-5, Op-Amps*
VI Oct 14 WED EXAM	EXAM-I Wednesday	EXAM-I: Basics, AC Circuits, Semiconductors, Op-amps		No Lab
VII Oct 21-23	Wed Lecture Magneto-electronics	Magnetic induction/flux Transformers (Ch-11)	11-all	*Lab-6, Build a Magnetometer*
VIII Oct 28-30	Wed Lecture Optoelectronics	Photodiode, LED, laser	none	*Lab-7, Optoelectronics* (coupled LED-photodiode)
IX Nov 2-6 MON/WED	Mon/Wed Lectures MON Digital-1 WED Digital-2	Digital Logic (Ch-19,22), Binary Numbers (Ch-54) Logical Networks (Ch-20)	19-all, 20-all	*Lab-8a, Digital Circuits* (truth table, 4-bit decoder)
X Nov 11-13	Wed Lecture Pulsed ICs	Lecture: Pulsed ICs Digital Summary	21-1/2	*Lab-8b, Pulsed Digital* (Flip-flops, counter, displays)
XI Nov 18-20 WED EXAM	EXAM-II - Wed Final Project	EXAM-II: Magnetoelectronics, Optoelectronics, Digital/Pulsed		*Final Project*
XII Nov 25-27	No Lecture	Thanksgiving		No Lab
XIII Dec 2	Wed Lecture	Future Electronics		*Project PowerPoint due Monday Dec 2* (EG361 or email file)
XIV Dec 7-9	No Classes			

All the information for the course can be obtained via the course **Calendar** at https://web.northeastern.edu/heiman/2371/index.html or thru Canvas.

Simply click on any of the following:

Lectures
Homework
Lab Experiments.

There are also links to the course **Syllabus** and **Description** at the top.

Electronics - PHYS 2371/2

Syllabus Highlights (see links in the website for more details)

When: **Lectures -** Wednesday (mostly) (2:50-4:30pm); **Labs** - Thursday (2:50-6:20), Friday (8:00-11:30; 1:35-5:05)

Where: **Lectures - West Village G 108**; **Labs - Dana 230**

Instructor: Profs. **Don Heiman** (Egan 361, heiman@neu.edu), Hari Kumarakuru h.kumarakuru@neu.edu

Office Hours: by arrangement; Zooms Mondays 2:50-4:30pm If you have questions, please request help at the earliest time. Contact us through email (best) or Canvas. Either the TA or the instructor will be in the lab for the entire lab time.

Textbook is NOT required, but recommended: Class notes and links to web information are usually sufficient.

Optional Textbook: *Electronics for Scientists ebook($83.70) or paper+ebook($103) from Academic Pub*
Click on Students and register with your email address as your username.
[Excerpted from Introduction to Modern Electronics, by William L. Faissler (Wiley, 1991)]

Homework: Seven homework sets will be assigned.
Homework is due on **Wednesday** at the beginning of class, following the week that it is assigned.

Lab Experiments: Eight lab Experiments and one Project will be completed during the semester. See links in Calendar.
There are two formats for the results of the Lab Experiments

- ***Worksheets:*** Results of the first four Lab Experiments will be written in a supplied Worksheet format.
- ***Reports:*** Results of the last four Lab Experiments will be written in a standardized Report format.
- ***Notebook:*** Basic information and observations are to be recorded in the digital file, Microsoft **OneNote**.
  Data should be recorded in **tables** (e.g. xls) and **plotted** as the data is recorded.

Due Dates:

- Worksheets and Reports are due on **Wednesdays** at the beginning of class, following the lab period.
- Homework is also due on **Wednesday** at the beginning of class, following the week that it was assigned.
- Grades for late Worksheets/Reports and late homework will be reduced 5% per late day.

Exams: Two midterm exams will be given and announced ahead of time.

Grading: Letter grading will be distributed on a curve. The following grading weights are approximate to 5 %.

- ***Homework:*** Several problems will be assigned each week and turned in for grading. (15 % of grade)
- ***Exams:*** Two exams will be given during the semester. (30 % of grade)
- ***Lab Results:*** Four Worksheets, four Reports and the Project are required. (55 % of grade)

Course Structure

Calendar go to: https://web.northeastern.edu/heiman/2371/index.html
: thru **Canvas**

Syllabus

Description

Textbook – not required

- excerpts from Faissler book
  ebook from AcademicPub ~$84

Labs (4 Worksheets, 4 Reports, Project)

- Template PHYS2372.doc

Questions?

Electronics - PHYS 2371/2

Topics Today

(1) Course structure

(2) Introduction/Background

(3) Electronics basics

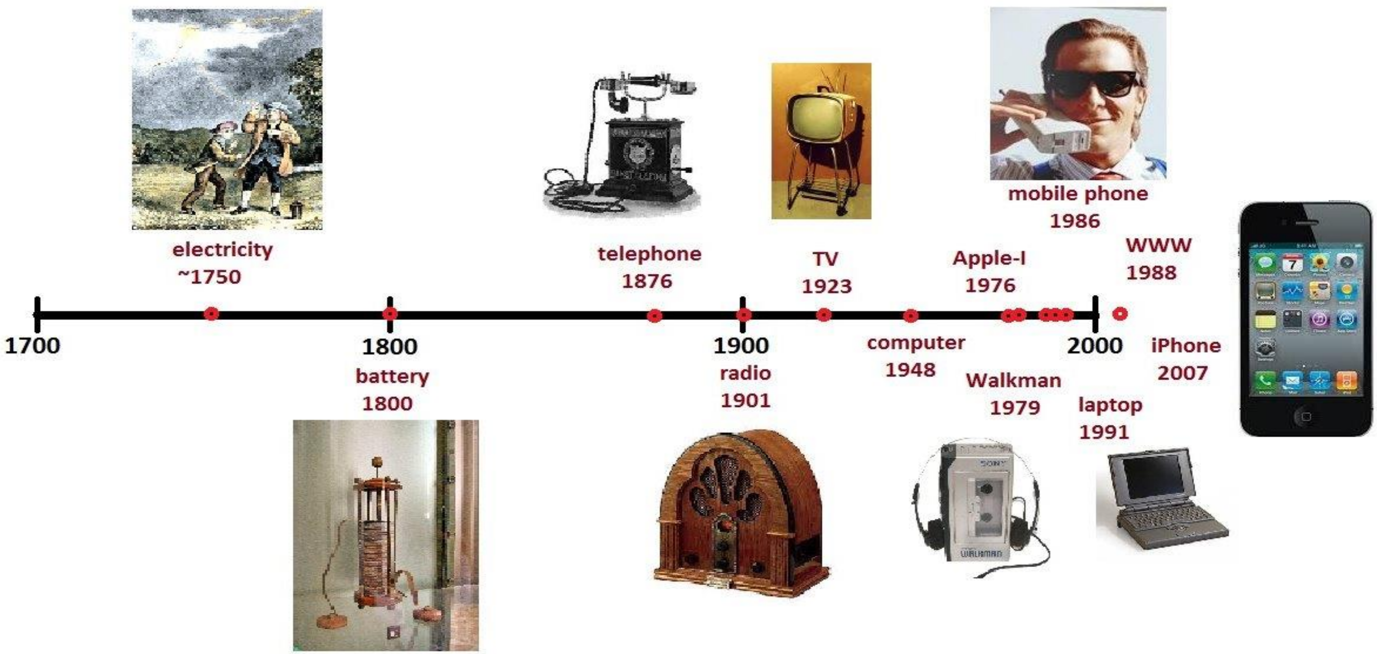
(4) First lab experiment

Electronics for Scientists

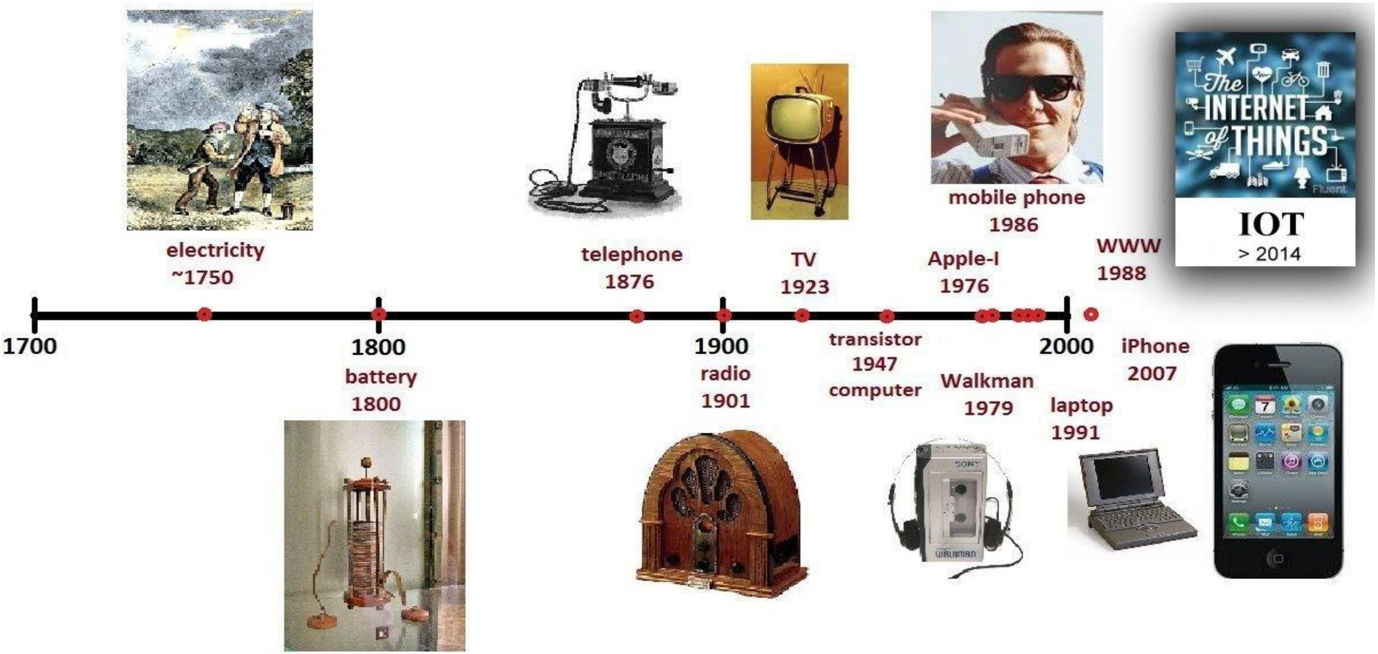
PHYS 2371 (Lectures)
PHYS 2372 (Labs)

(1) **What** is Electronics
(2) **Why study** Electronics
(3) **How** to understand the physics inside electronics

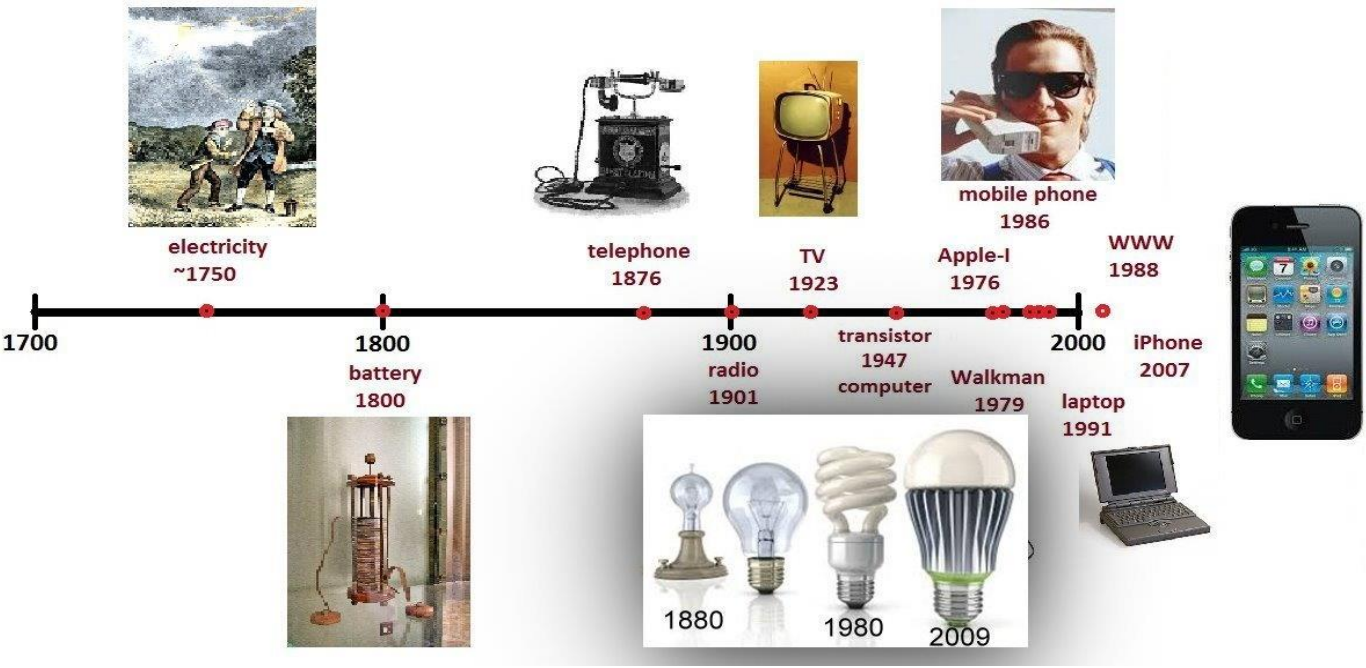
Electronics Timeline



Electronics Timeline



Electronics Timeline



Electronics - PHYS 2371/2

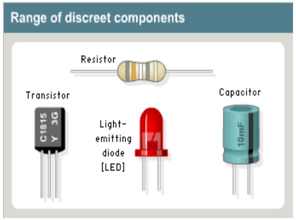
What is "Electronics" -- the science and technology concerned with the development, behavior, and applications of electronic devices and circuits for performing some **useful action**.

It is the technology involving the manipulation of electrons (**charge**) leading to **voltages** and **currents**.

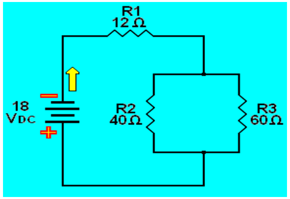
- discrete components (transistors, resistors, etc.)
- combine components into circuits
- integrate components into ICs (integrated circuits = chips)
- combine ICs into an electronic device (iPhone, radio, etc.)

iPhone

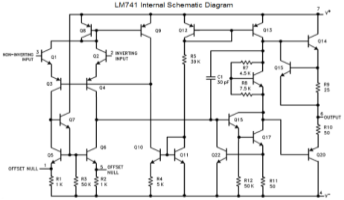
Discrete Components



Circuit



Integrated Circuit



Electronics is grouped into

I. Analog Electronics

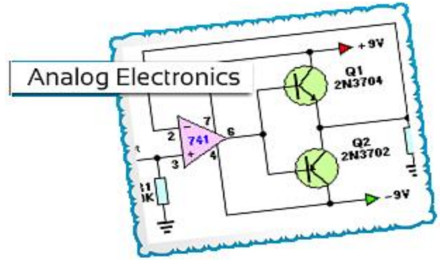
- voltages vary continuously
- amplify voltages or currents

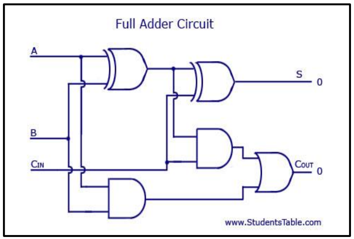
II. Digital Electronics

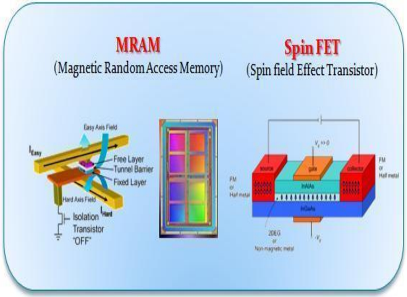
- voltage is 0 or $+V_o$
- binary logic bit = 0 or 1

III. Spintronics (Quantum World)

- electrons have magnetic moment
- hard disk drive (HDD) reader
- magnetic MRAM







Why Study Electronics

[Live CNN interview from the International Space Station with astronaut Karen Nyberg](), 2014

CNN: @FumaiMartin asks
how much physics and chemistry taught in school helps at the International Space Station?

KN: *I think any type of scientific class or mathematical class ... is helpful* ***even if you don't use the specific fundamentals*** *that you learn in that class.*

There is something about ***learning … a very broad spectrum****.*

…. a lot of the classes you take you are like,
*you think to yourself '****I'm never going to use this****.'*

And you know what, sometimes you don't ...
But a lot of it you do use*.*

Bottom line: *you often don't know what you are going to need in the future*.

Questions?

Electronics - PHYS 2371/2

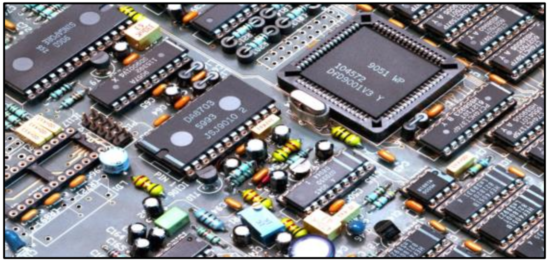
Topics Today

(1) Course structure

(2) Introduction/Background

(3) Electronics basics

(4) First lab experiment



Electronic Basics

- Review of stuff you learned in Physics-2
- Some background for the upcoming
  Worksheet-1 Experiment on Thursday/Friday

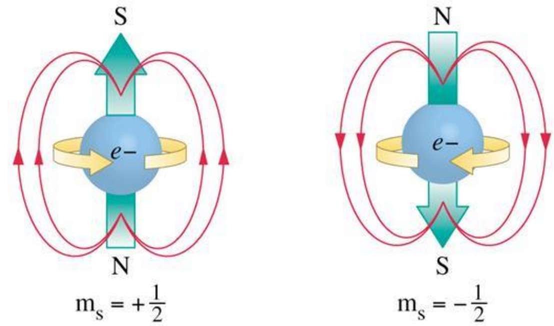
Physics of Electronics

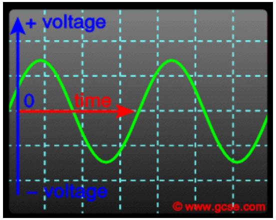
- **Electrons**
  - have mass, charge, spin (magnet)

- **Charge and Electric Field**
  - e = -1.6022E-19 C   (Ben Franklin)
  - charges set up an electric field which affects another charge by the

Electromotive Force (electron-electron)

$$F = k\, q_1\, q_2 / r^2$$

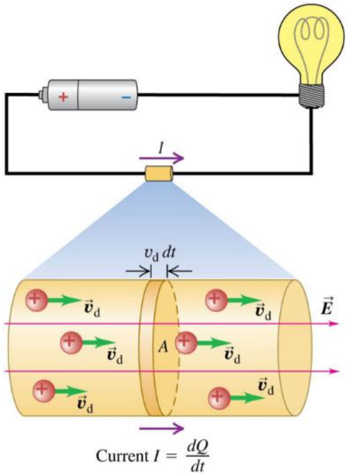


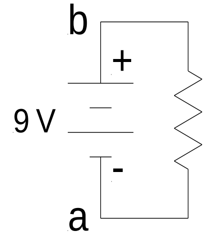


AC House Current
charge/voltage oscillates,
charge does not propagate
– Force (E-field) propagates

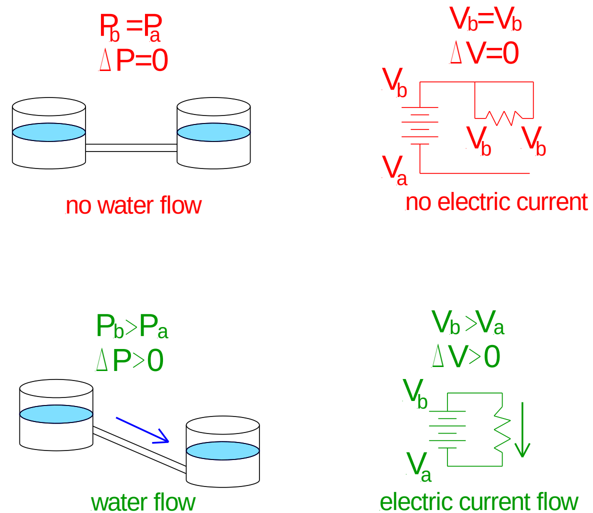
Physics of Electronics

- **Force on electron** -> Electric field
  - **F** = q **E**
  - direction depends on the sign of q
- **Current $I = \Delta Q/\Delta t$**
  - charge per unit time across A
  - amp (A), mA, μA
- **Voltage** -> potential difference
  - $\Delta V = V_b - V_a = W_{ab}/Q$
  - volt=joule/coulomb (V=J/C)
  - choose one common point, set to V_a=0





Water Analogy		Electricity
pipe	⟷	wire
pressure	⟷	voltage
flow rate	⟷	current



Typical Units

Voltage (volt) – **μV, mV, V**

Current (amp) – **μA, mA, A**

Resistance (ohm) – **Ω, kΩ, MΩ**

Capacitance (farad) – **pF, nF, μF**

Inductance (henry) – **μH, mH, H**

Frequency (*f*, hertz) – **Hz, kHz, MHz**
(ω, **radian/s** or **s^{-1}**)

T	tera	10^{12}
G	giga	10^{9}
M	**mega**	**10^{6}**
k	**kilo**	**10^{3}**
-		**1**
m	**milli**	**10^{-3}**
μ	**micro**	**10^{-6}**
n	**nano**	**10^{-9}**
p	**pico**	**10^{-12}**
f	femto	10^{-15}
a	atto	10^{-18}
z	zepto	10^{-21}

Instead of **0.0037 V**
or **$3.7\text{x}10^{-3}$ V**
Easier to use **3.7 mV**

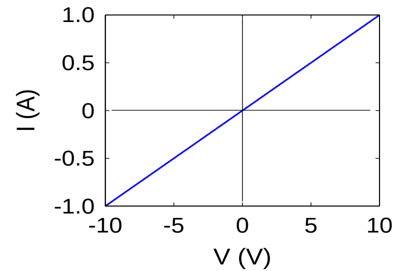
Instead of **$6.8\text{x}10^{4}$ Ω**
Easier to use **68 kΩ**
(without exponents)

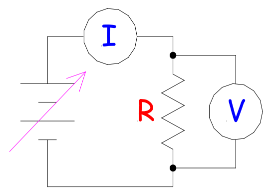
Electronic Basics

- **Resistance** (I proportional to V)
  - Ohm's Law, **R = V/I** Ω=V/A (J=σE)
    (usually refers to constant R)
- **Power**
  - P = dW/dt = d(VQ)/dt = V(dQ/dt) = VI
  - **P = IV** = I^2R = V^2/R
- **I-V plot** (current vs voltage)
  - V – independent variable (cause)
  - I – dependent variable (effect)
  - Ohms Law: V/I=constant=R
    (R is the inverse of the slope)

Space Heater or Hair Dryer
V=120 VAC, I=15 A
P=VI=120*15 = **1800 W**

Electric Stove or Clothes Dryer
V=220 VAC, I=30 A
P=220*30 = **6.6 kW**





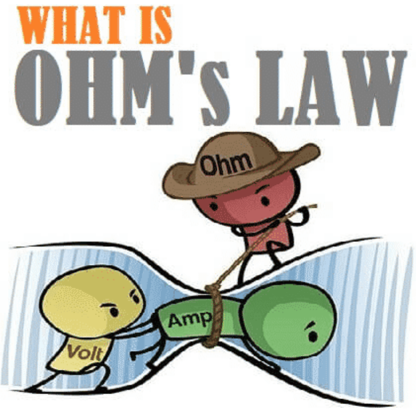
Ohm's Law

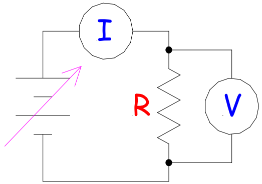
I = V/R

- ❑ **EVERY IMPORTANT !**

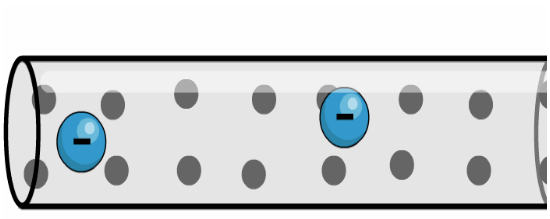
  When you apply a voltage
  - resistance determines the current
  - **you cannot vary both V and I independently**

  "It's the LAW"

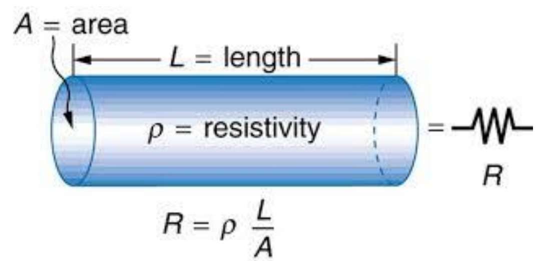




Resistance in a Wire



Material	ρ (Ωcm)
metal (Cu)	10^{-6}
semiconductor	10^{-4} – 10^{+4}
insulator (glass)	10^{+18}



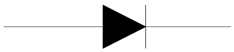
❑ **Resistivity ρ** (Ω-cm)

- ρ is a "material property" does not depend on how much material
- resistance of a wire **R = ρ L/A**

$R=\rho L/A=2E\text{-}8\ (\Omega m)\ L/(\pi D^2/4)$

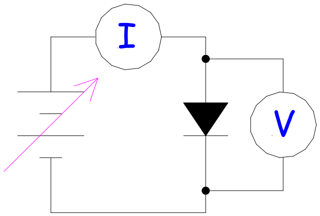
Cu wire, L=0.1 m long
R=0.005 Ω 36-gauge (D=0.13 mm)

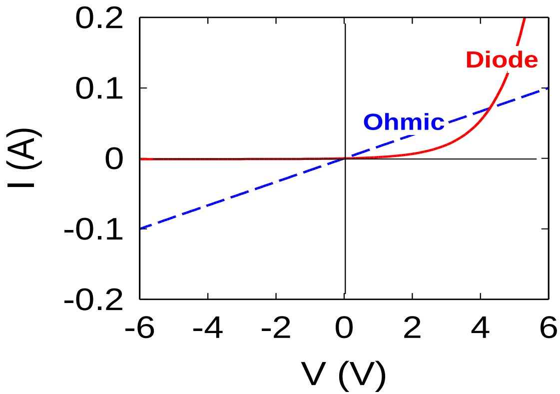
Cu wire, L=1 m long
R=0.013 Ω 18-gauge (D=1 mm)



- **Diode**
  - semiconductor *p-n* junction
  - thermionic emission over energy barrier

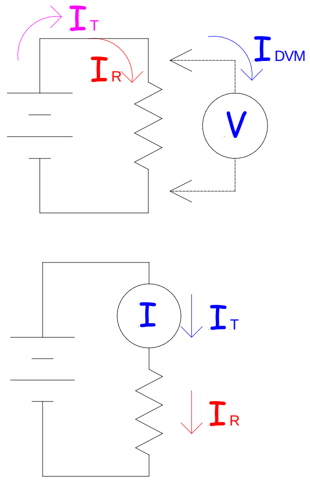
  - nonlinear I(V), non-Ohmic
  - $I = I_s\,[\exp(eV/k_BT) - 1]$





Digital Multimeter (DMM)

- **DVM** - Digital **Volt** Meter
  in PARALLEL with component
  - high resistance, $R_{DVM} >> R_?$
  - **$R_{DVM} \sim 10^7\ \Omega$** (10 MΩ)
  - don't want any current to flow **thru meter**
  - $I_T >> I_{DVM}$ ($I_T = I_R + I_{DVM}$)
- **DCM** - Digital **Current** Meter
  in SERIES with component
  - low resistance, $R_{DCM} << R$
  - **$R_{DCM} \sim 10^{-1}\ \Omega$**
  - don't want any voltage drop **across meter**
  - $I_T = I_R$

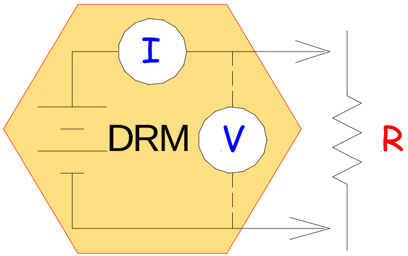


What happens if you put a DVM in series with a resistor?

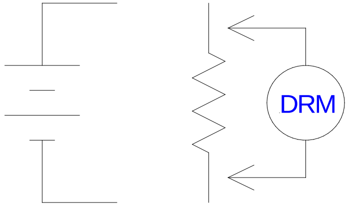
What happens if you put a DCM in parallel with a resistor?

Multimeters

- **Ohm Meter** - Digital **Resistance** Meter
  - applies a known current
  - measures the voltage it uses to produce that current
  - uses Ohm's law to compute R=V/I

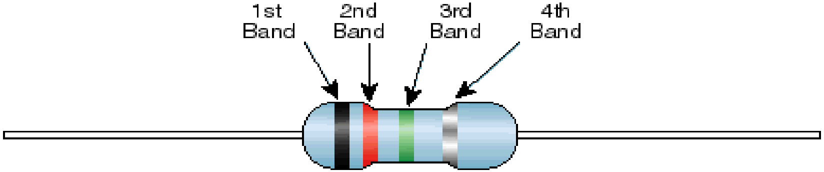


- **IMPORTANT**
  - remove resistor from circuit
  - current from a circuit must **not** flow thru resistor



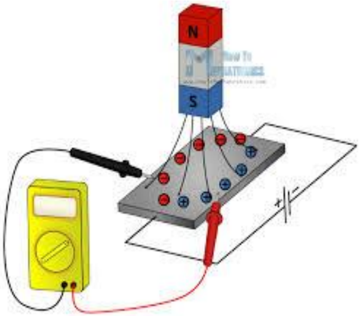
Resistor Color Code

Standard EIA Color Code Table **4 Band:** ±2%, ±5%, and ±10%



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Chart Provided By XICON

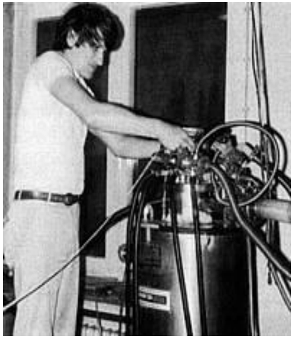


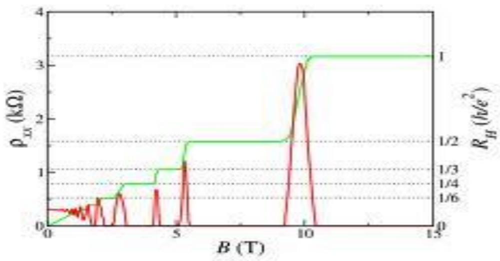
Universal Resistance Standard

Discovered in 1980 by Klaus von Klitzing

Integer Quantum Hall Effect

$R_K = h/e^2 =$ **25,812.807557(18)** Ω





1985

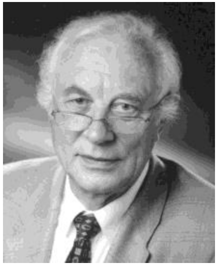
Nobel Prize

In 1968, Professor Gottfried Landwehr of the Physical Institute wrote to student Klaus von Klitzing:

"As I am sure you have already heard from Dr. Braun, I would be glad to have you come to Würzburg next year, in order to work on your doctoral project with me. [...]

We expect to have large amounts of liquid helium at our disposal as of March, 1969. [...]

In our experience, a good experimental PhD project requires approximately three years.



Questions?

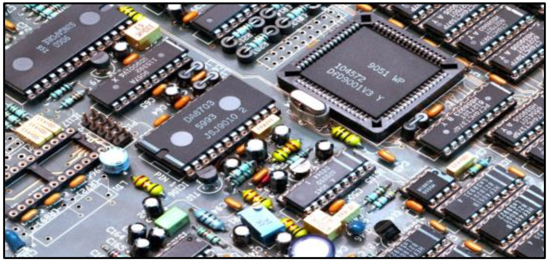
Topics Today

(1) Course structure

(2) Introduction/Background

(3) Electronics basics

(4) First lab experiment



Electronics - PHYS 2371/2

Worksheet-1
Electronics
Introduction

First lab experiment this Thursday/Friday.

e-notebook
MS OneNote

Put in:
WORD text,
EXCEL data,
plots.

Worksheet-1, Electronics Introduction Name: ____________________

Physics PHYS 2371/2372, Electronics for Scientists
Don Heiman, Northeastern University

This lab is a review, at a somewhat deeper level, of things that you have probably seen or heard in the freshman courses and labs. You will use Digital Multimeters (DMM) to study some simple circuit elements, their characteristics, and the behavior of some combinations of these. You will also get a sense of possible complications when you introduce measuring instruments into a circuit, since the measuring instrument is an additional component that can alter the properties of a circuit.

You should arrange your data in well-designed tables.
Don't just write down numbers – include units (V or mV, mA or μA).

For this Lab, and most other Labs, you will need the following:

- Variable DC power supply (PS) (12 or 15 V, 0.5 A)
- 2 DMMs (Digital MultiMeter)
- Resistors (kΩ range; one 10 Ω, 1 W), capacitors (10-100 μF)
- Flashlight bulb in holder, diode

++

I. DMM Basics

1. What are the maximum and minimum (set V=0) DVM measured DC voltages from the PS?
   V(max) = ______________; V(min) = ________________
2. What do you find when you set the DVM to read AC when setting the maximum PS voltage?
   V(AC) = ________________
3. Pick a resistor in the kΩ range. What are the following?
   R(color code) = __________; R(DMM) _______________

Worksheet-1, Electronics Introduction Name: ___________________________

Physics PHYS 2371/2372, Electronics for Scientists
Don Heiman and Hari Kumarakuru, Northeastern University

This lab is a review, at a somewhat deeper level, of things that you have probably seen or heard in the freshman courses and labs. You will use Digital Multimeters (DMM) to study some simple circuit elements, their characteristics, and the behavior of some combinations of these. You will also get a sense of possible complications when you introduce measuring instruments into a circuit, since the measuring instrument is an additional component that can alter the properties of a circuit.

In any scientific work, record keeping is a basic requirement. It is important that you carefully record: (1) the instruments used; (2) the measurement configuration and circuits; (3) all raw data (in tables); and (4) preliminary analysis. Put these in your e-notebook (OneNote). You should arrange your data in well-designed tables. **Don't just write down numbers – include units** (V or mV, mA or μA).

For this Lab, and most other Labs, you will need the following:

- Variable DC power supply (PS) (12 or 15 V, 0.5 A)
- 2 DMMs (Digital MultiMeter)
- Resistor (kΩ range)
- Flashlight bulb in holder, semiconductor diode (1N400X)

++

I. DMM Basics

1. What are the maximum (set max V) and minimum (set V=0) DVM measured DC voltages from the PS?

Worksheet-1, Electronics Introduction Name: ___________________________

Physics PHYS 2371/2372, Electronics for Scientists
Don Heiman and Hari Kumarakuru, Northeastern University

This lab is a review, at a somewhat deeper level, of things that you have probably seen or heard in the freshman courses and labs. You will use Digital Multimeters (DMM) to study some simple circuit elements, their characteristics, and the behavior of some combinations of these. You will also get a sense of possible complications when you introduce measuring instruments into a circuit, since the measuring instrument is an additional component that can alter the properties of a circuit.

In any scientific work, record keeping is a basic requirement. It is important that you carefully record: (1) the instruments used; (2) the measurement configuration and circuits; (3) all raw data (in tables); and (4) preliminary analysis. Put these in your e-notebook (OneNote). You should arrange your data in well-designed tables. **Don't just write down numbers – include units** (V or mV, mA or μA).

For this Lab, and most other Labs, you will need the following:

- Variable DC power supply (PS) (12 or 15 V, 0.5 A)
- 2 DMMs (Digital MultiMeter)
- Resistor (kΩ range)
- Flashlight bulb in holder, semiconductor diode (1N400X)

+++

I. DMM Basics

1. What are the maximum (set max V) and minimum (set V=0) DVM measured DC voltages from the PS?

Worksheet-1
Electronics Introduction

I. The DMM (Digital MultiMeter)

- one to measure voltage (DVM)
- one to measure current (DCM)

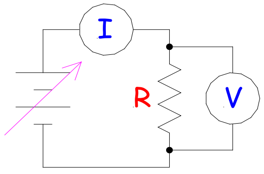
II. Resistance Measurement

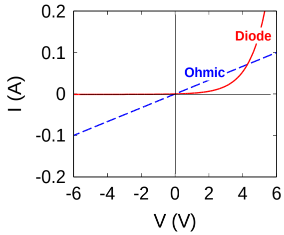
- use power supply (PS), DVM, DCM
- use Ohm's law to compute R=V/I

III. I-V Characteristics

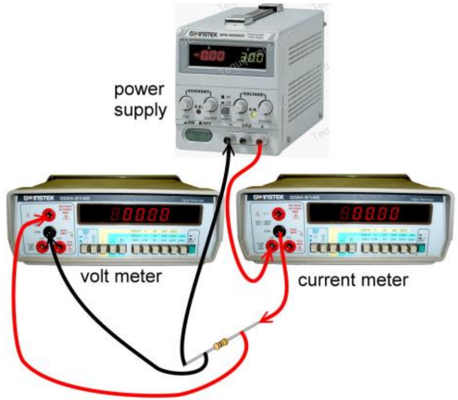
- **resistor, diode, light bulb**
- compute maximum voltage V_{MAX} using $P=V_{MAX}^2/R$ for P=1/2 W resistor
- set V and measure I
- do not exceed V_{MAX} for the resistor
- do not exceed **6 V** for the light bulb
- Caution: bulb gets **HOT**

(1) SKETCH CIRCUIT FIRST





(2) Attach CURRENT meter
(3) Attach VOLT meter



Questions?

The lab is limited to only 13 students at a time, which is about one-half of the enrolled students.

Students who want to come into the lab to do the experiments will be determined on a first-come first-serve basis.

Other students can watch the experiments remotely in a video.

The End