PHYS 1444 – Section 002
Lecture 13

Wednesday, Oct. 9, 2019

Dr. Jaehoon Yu

CH 25

- Ohm's Law: Resisters, Resistivity
- Electric Power
- Alternating Current
- Microscopic View of Electric Current
- Ohm's Law in Microscopic View
- EMF and Terminal Voltage

Announcements

- Reading Assignments: CH25.9 and 25.10
- Mid-term exam
  - Wednesday, Oct. 16 at the beginning of the class
  - Comprehensive exam which covers CH21.1 through what we cover in class Monday, Oct. 14 + the math refresher in A1 – A8
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the quiz
  - No derivations, word definitions, set ups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- Mid-term grade discussions
  - From 12:00 – 2:30pm, Wednesday, Oct. 24 in my office (CPB342)
  - Last name starts with A – D (12 – 12:30), E– K (12:30 – 1), L – O (1 – 1:30), P – S (1:30 – 2:00), T – Z (2-2:30)
- Quiz 2 results
  - Class average: 27.4/60 equivalent to 45.7/100; previous result: 56.4/100; Class top: 59/60
- Colloquium at 4pm today: Dr. P. Jena of Virginia Commonwealth Univ.

UNIVERSITY OF TEXAS ARLINGTON

PHYSICS DEPARTMENT

Colloquium:

Many Faces of Carbon

Carbon, the basis of all life on the Earth, is one of the most fascinating elements in the periodic table. The unique properties of carbon emerge from its ability to form diverse spn ($1 < n < 3$) bonds, graphite with sp2 and diamond with sp3 bonding being the most common forms. The discovery of zero-dimensional (0D) carbon fullerenes, one-dimensional (1D) chain-like polymer called "carbyne" and carbon nanotube, and two-dimensional (2D) graphene, all with novel properties characteristic of their reduced dimensionality and size, has ushered a new era in carbon science. In recent years many new metastable forms of carbon exhibiting a mixture sp1, sp2 and/or sp3 bonding pattern have also emerged. In this talk I will focus on the carbon allotropes that have been studied in our group1-6. These include functionalized C60 fullerenes for hydrogen storage1, 2, semi-hydrogenated graphene for metal-free ferromagnet3, 3D metallic carbon made of hybridized sp2 and sp3 bonded atoms4, and a Cairo-tilling inspired quasi-2D penta-graphene made only of carbon pentagons5. I will highlight the discovery6 of a new carbon allotrope that resulted from the synergy between theory and experiment and can be viewed as a cousin of penta-graphene. Interestingly, unlike penta-graphene, this new carbon allotrope is semi-metallic and magnetic. Theoretical studies were carried out using gradient corrected density functional theory while experiment was conducted using an organic precursor molecule. Thermodynamic stabilities of the above carbon allotropes are confirmed by total energy calculations and ab initio molecular dynamics. Potential applications of some of these carbon allotropes will be discussed.

Puru Jena
Virginia Commonwealth University

WEDNESDAY, OCTOBER 9
4PM ROOM 100 SCIENCE HALL
REFRESHMENTS AT 3:30PM IN 108 SCIENCE HALL

MAVERICK SCIENCE
UNIVERSITY OF TEXAS ARLINGTON
Innovate, Discover, Learn

Special Extra Credit #4

- **Civic Duty Participation Exercise**
- You can submit up to four "I Voted" stickers for 20 points total
- Be sure to tape one side of the stickers on a sheet of paper with your name on it along with the following info for each sticker
  - The number and the name of the precinct the vote was cast
  - The full name of the person voted next to the relevant sticker
  - The signature of the person voted next to the full name
- None of the stickers can be from the same person on someone else's extra credit or yours
- Deadline: Beginning of the class Wednesday, Nov. 6

The Nobel Prize in Physics 2019

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2019

"for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos"

with one half to

James Peebles
Princeton University, USA

"for theoretical discoveries in physical cosmology"

and the other half jointly to

Michel Mayor
University of Geneva, Switzerland

Didier Queloz
University of Geneva, Switzerland
University of Cambridge, UK

"for the discovery of an exoplanet orbiting a solar-type star"

New perspectives on our place in the universe

This year's Nobel Prize in Physics rewards new understanding of the universe's structure and history, and the first discovery of a planet orbiting a solar-type star outside our solar system.

James Peebles' insights into physical cosmology have enriched the entire field of research and laid a foundation for the transformation of cosmology over the last fifty years, from speculation to science. His theoretical framework, developed since the mid-1960s, is the basis of our contemporary ideas about the universe.

The Big Bang model describes the universe from its very first moments, almost 14 billion years ago, when it was extremely hot and dense. Since then, the universe has been expanding, becoming larger and colder. Barely 400,000 years after the Big Bang, the universe became transparent and light rays were able to travel through space. Even today, this ancient radiation is all around us and, coded into it, many of the universe's secrets are hiding. Using his theoretical tools and calculations, James Peebles was able to interpret these traces from the infancy of the universe and discover new physical processes.

The results showed us a universe in which just five per cent of its content is known, the matter which constitutes stars, planets, trees – and us. The rest, 95 per cent, is unknown dark matter and dark energy. This is a mystery and a challenge to modern physics.

In October 1995, **Michel Mayor** and **Didier Queloz** announced the first discovery of a planet outside our solar system, an exoplanet, orbiting a solar-type star in our home galaxy, the Milky Way. At the Haute-Provence Observatory in southern France, using custom-made instruments, they were able to see planet 51 Pegasi b, a gaseous ball comparable with the solar system's biggest gas giant, Jupiter.

This discovery started a revolution in astronomy and over 4,000 exoplanets have since been found in the Milky Way. Strange new worlds are still being discovered, with an incredible wealth of sizes, forms and orbits. They challenge our preconceived ideas about planetary systems and are forcing scientists to revise their theories of the physical processes behind the origins of planets. With numerous projects planned to start searching for exoplanets, we may eventually find an answer to the eternal question of whether other life is out there.

This year's Laureates have transformed our ideas about the cosmos. While James Peebles' theoretical discoveries contributed to our understanding of how the universe evolved after the Big Bang, Michel Mayor and Didier Queloz explored our cosmic neighbourhoods on the hunt for unknown planets. Their discoveries have forever changed our conceptions of the world.

James Peebles, born 1935 in Winnipeg, Canada. Ph.D. 1962 from Princeton University, USA. Albert Einstein Professor of Science at Princeton University, USA.

Michel Mayor, born 1942 in Lausanne, Switzerland. Ph.D. 1971 from University of Geneva, Switzerland. Professor at University of Geneva, Switzerland.

Didier Queloz, born 1966. Ph.D. 1995 from University of Geneva, Switzerland. Professor at University of Geneva, Switzerland and University of Cambridge, UK.

Prize amount: 9 million Swedish krona, with one half to James Peebles and the other half jointly to Michel Mayor and Didier Queloz
Further information: www.kva.se and www.nobelprize.org
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The Royal Swedish Academy of Sciences, founded in 1739, is an independent organisation whose overall objective is to promote the sciences and strengthen their influence in society. The Academy takes special responsibility for the natural sciences and mathematics, but endeavours to promote the exchange of ideas between various disciplines.

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THE ROYAL SWEDISH ACADEMY OF SCIENCES

Direction of the Electric Current

- What do conductors have in abundance?
  - Free electrons
- What happens if a continuous loop of conducting wire is connected to the terminals of a battery?
  - Electrons start flowing through the wire continuously as soon as both the terminals are connected to the wire. Why?
    - The potential difference between the battery terminals sets up an electric field inside the wire and in the direction parallel to the field
    - Free electrons in the conducting wire get attracted to the positive terminal
    - The electrons leaving negative terminal flow through the wire and arrive at the positive terminal
      - Electrons flow from negative to positive terminal
  - Due to historical convention, the direction of the current is opposite to the direction of flow of electrons ➔ Conventional Current

Ohm's Law: Resistance and Resistors

- What do we need to produce electric current?
  - Potential difference
- Georg S. Ohm experimentally established that the current is proportional to the potential difference ($I \propto V$)
  - If we connect a wire to a 12V battery, the current flowing through the wire is twice that of 6V, three times that of 4V and four times that of 3V battery.
  - What happens if we reverse the sign of the voltage?
    - It changes the direction of the current flow
    - Does not change the magnitude of the current
  - Just as in water flow case, if the height difference is large the flow rate is large ➔ If the potential difference is large, the current is large.

Ohm's Law: Resistance

- The exact amount of the current flow in a wire depends on
  - The voltage
  - The resistance of the wire to the flow of electrons
    - Just like the gunk in water pipe slows down water flow
    - Electrons are slowed down due to interactions with the atoms of the wire
- The higher the resistance, the less the current for the given potential difference V
  - So how would you define resistance?
    - Such that current is inversely proportional to the resistance

$$\boxed{R = \frac{V}{I}}$$

Unit?

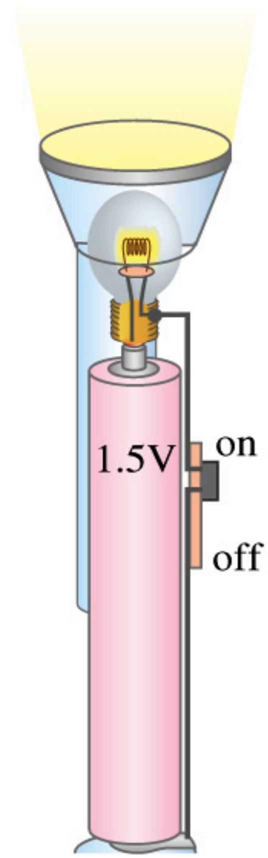
ohms Ω

$$1.0\Omega = 1.0V/A$$

  - Often it is rewritten as $\boxed{V = IR}$ Ohm's Law
  - What does this mean?
    - The metal conductor's resistance R is a constant independent of V.
  - This linear relationship is not valid for some materials like diodes, vacuum tubes, transistors etc. ➔ These are called non-ohmic

Example 25 – 4

Flashlight bulb resistance: A small flashlight bulb draws 300mA from its 1.5V battery. (a) What is the resistance of the bulb? (b) If the voltage drops to 1.2V, how would the current change?



From Ohm's law, we obtain

$$R = \frac{V}{I} = \frac{1.5V}{300mA} = \frac{1.5V}{0.3A} = 5.0\Omega$$

Would the current increase or decrease, if the voltage reduces to 1.2V?

If the resistance did not change, the current is

$$I = \frac{V}{R} = \frac{1.2V}{5.0\Omega} = 0.24A = 240mA$$

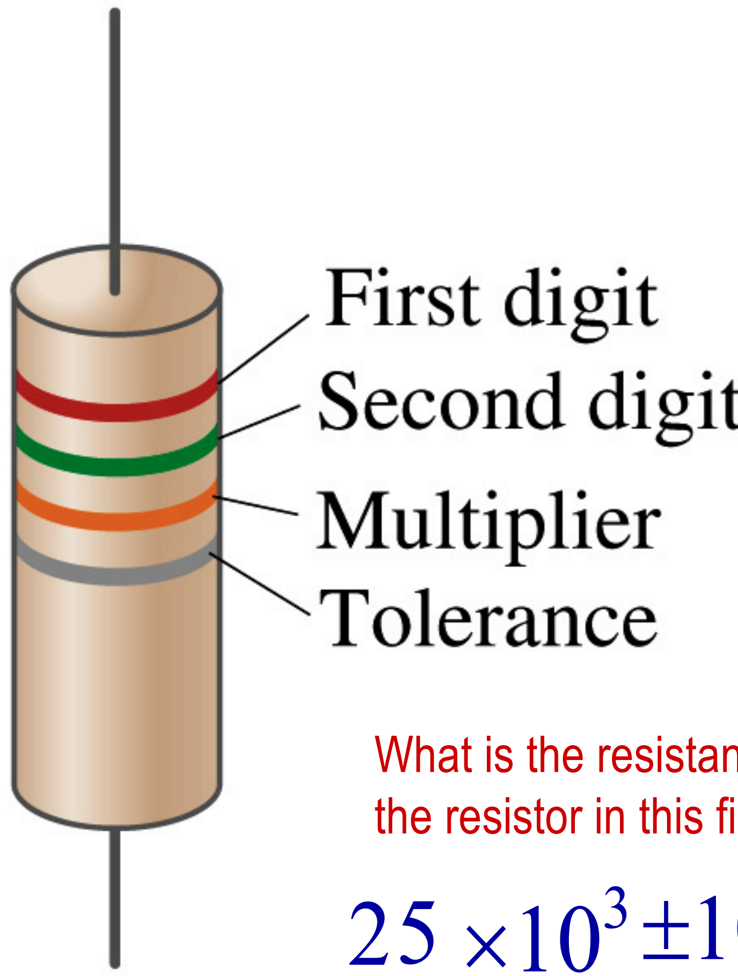
Ohm's Law: Resistors

- All electric devices offer resistance to the flow of current.
  - Filaments of light bulbs or heaters are wires with high resistance to cause electrons to lose their energy in the wire
  - In general connecting wires have lower resistance compared to other devices in the circuit
- In circuits, resistors are used to control the amount of current
  - Resistors offer resistance of less than one ohm to millions of ohms
  - Main types are
    - "wire-wound" resistors which consists of a coil of fine wire
    - "composition" resistors which are usually made of semiconductor carbon
    - thin metal films
- When drawn in the circuit, the symbol for a resistor is: 
- Wires are drawn simply as straight lines

Ohm's Law: Resistor Values

- Resistors have its resistance color-coded on its body
- The color-coding follows the convention below:

Color	Number	Multiplier	Tolerance
Black	0	$1=10^0$	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
None			20%

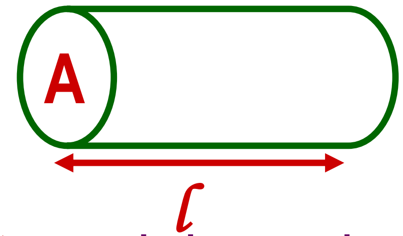


What is the resistance of the resistor in this figure?

$$25\times10^3\pm10\%$$

Resistivity

- It is experimentally found that the resistance R of a metal wire is directly proportional to its length ℓ and inversely proportional to its cross-sectional area A
  - How would you formularize this? $\boxed{R = \rho \frac{l}{A}}$

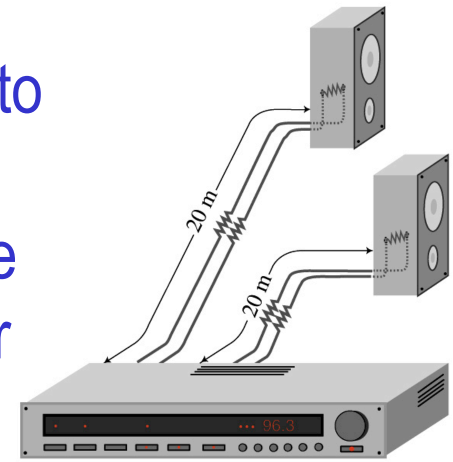


  - The proportionality constant ρ is called the **resistivity** and depends on the material used. What is the unit of this constant?
    - ohm-m or Ω–m
    - The values depends on purity, heat treatment, temperature, etc
  - How does the resistance change depending on the resistivity?
    - The higher the resistivity the higher the resistance
    - The lower the resistivity the lower the resistance and the higher the conductivity ➔ Silver has the lowest resistivity.
      - So silver is the best conductor
  - The reciprocal of the resistivity is called **conductivity**, σ,

$$\boxed{\sigma = \frac{1}{\rho}}$$

Example 25 – 5

Speaker wires: Suppose you want to connect your stereo to remote speakers. (a) If each wire must be 20m long, what diameter copper wire should you use to keep the resistance less than 0.1-Ω per wire? (b) If the current on each speaker is 4.0A, what is the voltage drop across each wire?



The resistivity of a copper is $\rho_{Cu} = 1.68 \times 10^{-8}\,\Omega \cdot m$ Table 25.1

From the formula for resistance, we can obtain the formula for area

$$R = \rho \frac{l}{A}$$

Solve for A

$$A = \rho \frac{l}{R} = \pi r^2$$

Solve for d

$$d = 2r = 2\sqrt{\frac{\rho l}{\pi R}} = 2\sqrt{\frac{1.68 \times 10^{-8}\,\Omega \cdot m \cdot 20m}{\pi \cdot 0.1\Omega}} = 2.1 \times 10^{-3}\,m = 2.1mm$$

From Ohm's law, V=IR, we obtain

$$V = IR = 4.0A \cdot 0.1\Omega = 0.4V$$

Example 25 – 6

Stretching changes resistance: A wire of resistance R is stretched uniformly until it is twice its original length. What happens to its resistance?

What is the constant quantity in this problem? The volume!

What is the volume of a cylinder of length L and radius r? $V = AL = \pi r^2 L$

What happens to A if L increases factor two, L'=2L?

The cross-sectional area, A, halves. A'=A/2

The original resistance is $R = \rho \frac{l}{A}$

The new resistance is $R' = \rho \frac{L'}{A'} = \rho \frac{2L}{A/2} = 4\rho \frac{L}{A} = 4R$

The resistance of the wire increases by a factor of four if the length increases twice.

Temperature Dependence of Resistivity

- Do you think the resistivity depends on temperature?
  - Yes
- Would it increase or decrease with the temperature?
  - Increase
  - Why?
  - Because the atoms are vibrating more rapidly as temperature increases and are arranged in a less orderly fashion. So?
    - They might interfere more with the flow of electrons.
- If the temperature change is not too large, the resistivity of metals usually increase nearly linearly with temperature

$$\boxed{\rho_T = \rho_0 \left[1 + \alpha\left(T - T_0\right)\right]}$$

  - α is the temperature coefficient of resistivity
  - α of some semiconductors can be negative due to increased number of freed electrons.

Electric Power

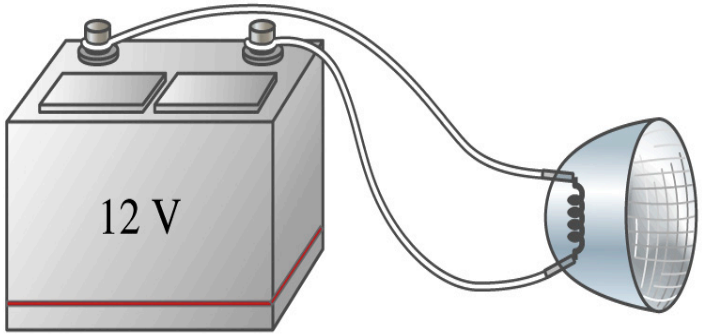
- Why is the electric energy useful?
  - It can transform into different forms of energy easily.
    - Motors, pumps, etc, transform electric energy to mechanical energy
    - Heaters, dryers, cook-tops, etc, transforms electricity to thermal energy
    - Light bulb filament transforms electric energy to light energy
      - Only about 10% of the energy turns to light and the 90% lost via heat
      - Typical household light bulb and heating elements have resistance of order a few ohms to a few hundred ohms
- How does the electric energy transforms to thermal energy?
  - Flowing electrons collide with the vibrating atoms of the wire.
  - In each collision, part of electron's kinetic energy is transferred to the atom it collides
  - KE of wire's bound atoms increases, and thus the temperature of the wire increases.
  - The increased thermal energy can be transferred as heat through conduction and convection to the air in a heater or to food on a pan, through radiation to bread in a toaster or radiated as light.

Electric Power

- How do we find out the power transformed by an electric device?
  - What is definition of the power?
    - The rate at which work is done or the energy is transformed
- What is the energy transformed when an infinitesimal charge dq moves through a potential difference V?
  - dU=Vdq
  - If dt is the time required for an amount of charge dq to move through the fixed potential difference V, the power P is
  - $P = dU/dt = V dq/dt$ ← **What is this?**
  - Thus, we obtain $\boxed{P = VI}$. **In terms of resistance** $\boxed{P = I^2 R = \frac{V^2}{R}}$
  - What is the unit? **Watts = J/s**
  - What kind of quantity is the electrical power?
    - Scalar
  - <u>P=IV can apply to any devices while the formula with resistance can only apply to devices that has resistance.</u>

Example 25 – 8

Headlights: Calculate the resistance of a 40-W automobile headlight designed for 12V.



Since the power is 40W and the voltage is 12V, we use the formula with V and R.

$$\boxed{P = \frac{V^2}{R}} \xrightarrow{\text{Solve for R}} R = \frac{V^2}{P} = \frac{(12V)^2}{40W} = 3.6\Omega$$

- What is the resistance of the filament of a 60W bulb?
- A 60W equivalent LED bulb draws 9.5W power. What is its resistance?
- A 100W equivalent LED bulb draws 17.5W power. What is its resistance?