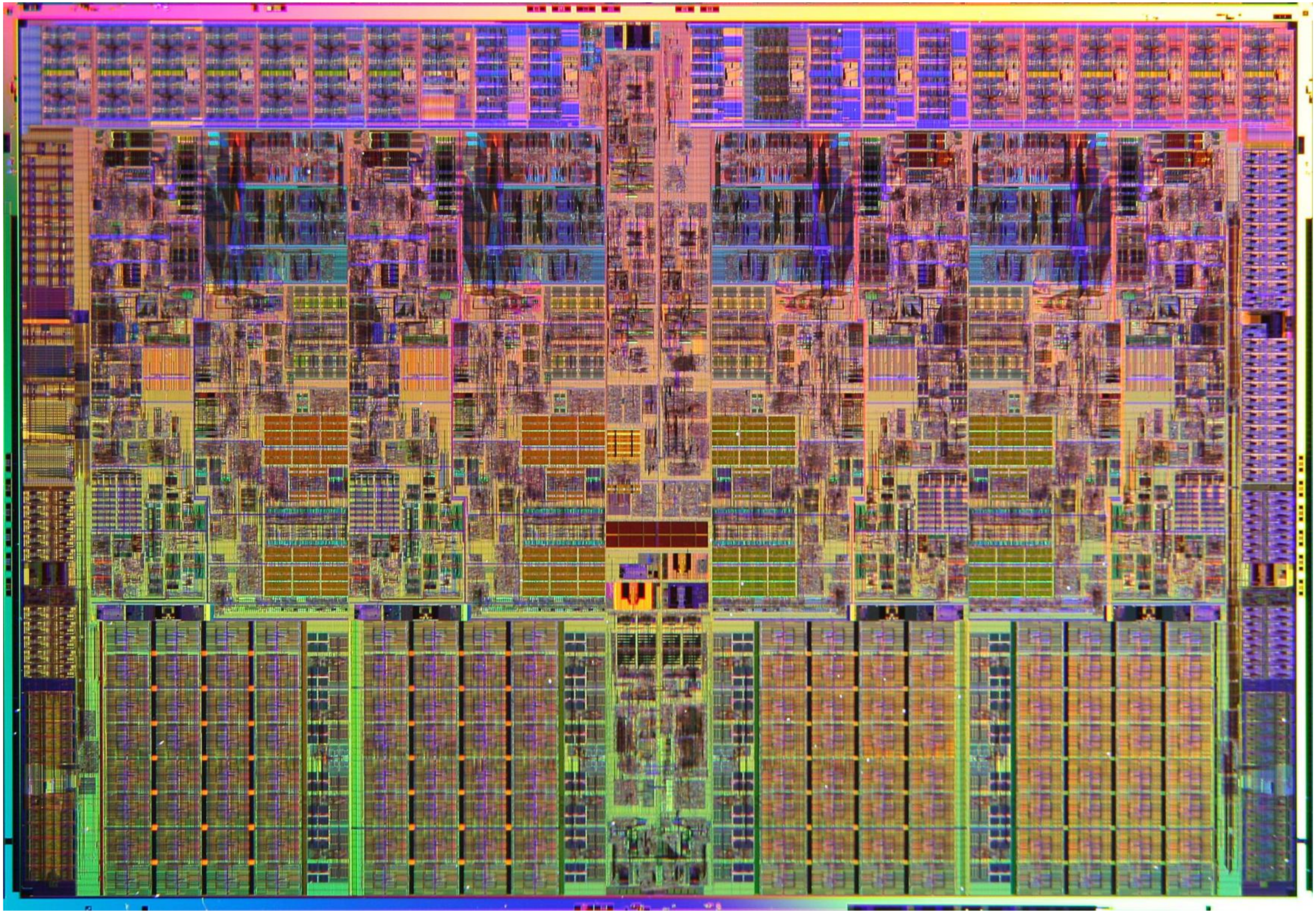
Introduction to Microelectronic Circuits
EE40
Lecture 1
Josh Hug

6/21/2010

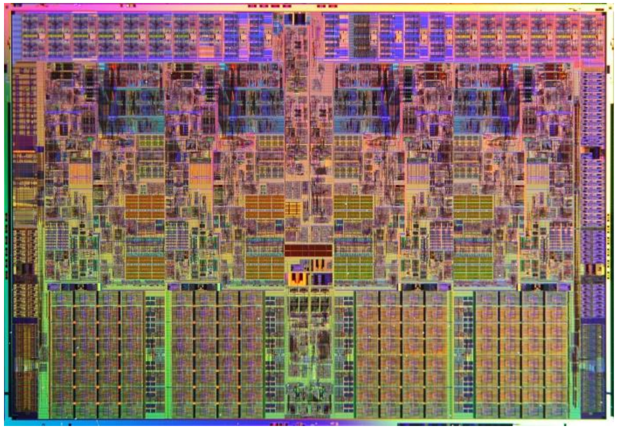
A Story

Integrated Circuit (Core i7 processor)



Courtesy of Intel

Integrated Circuits (Core i7 processor)



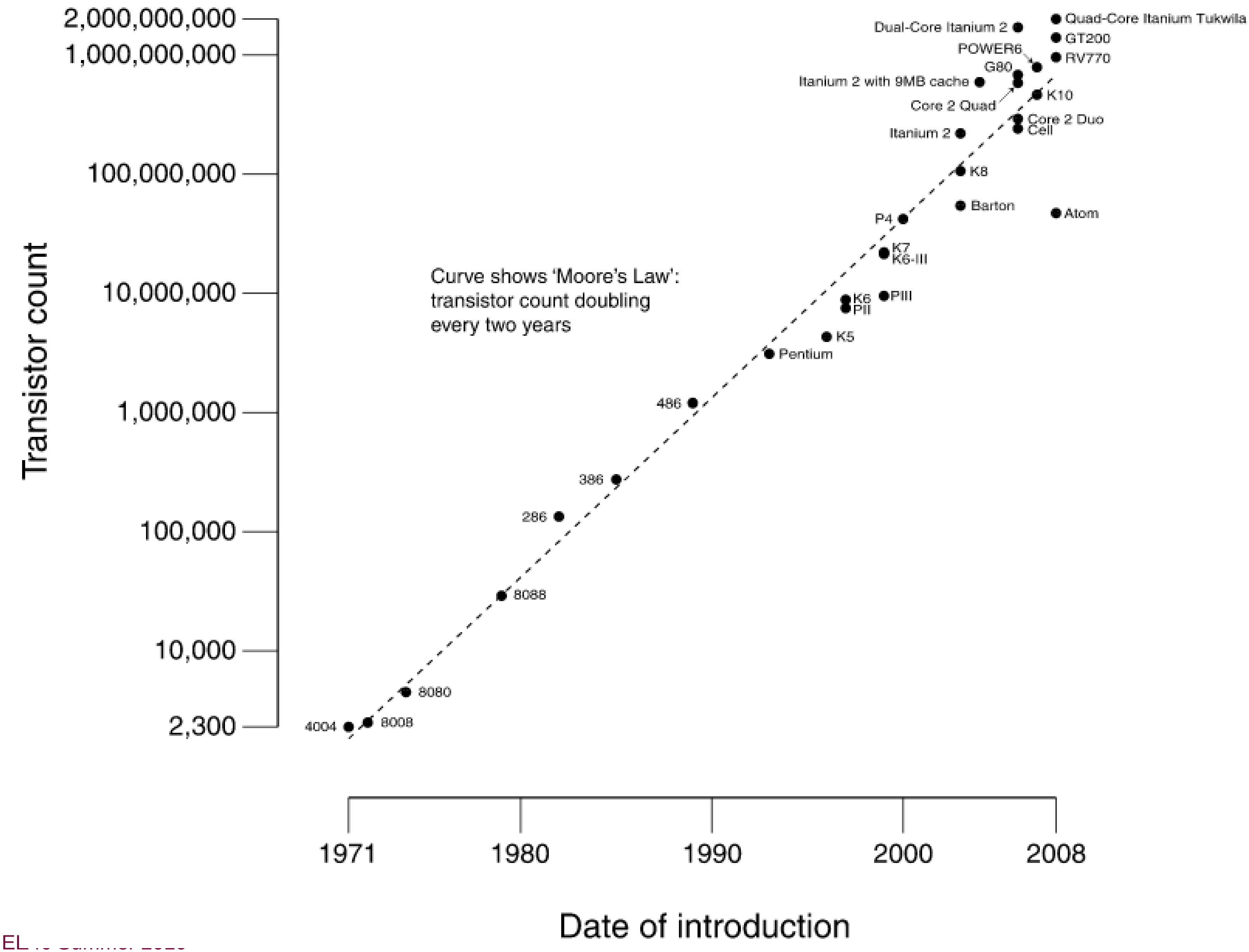
Almost 1,000,000,000 transistors
Features as small as a nanometer

Then (C64, 1983) and Now (iPhone, 2010)

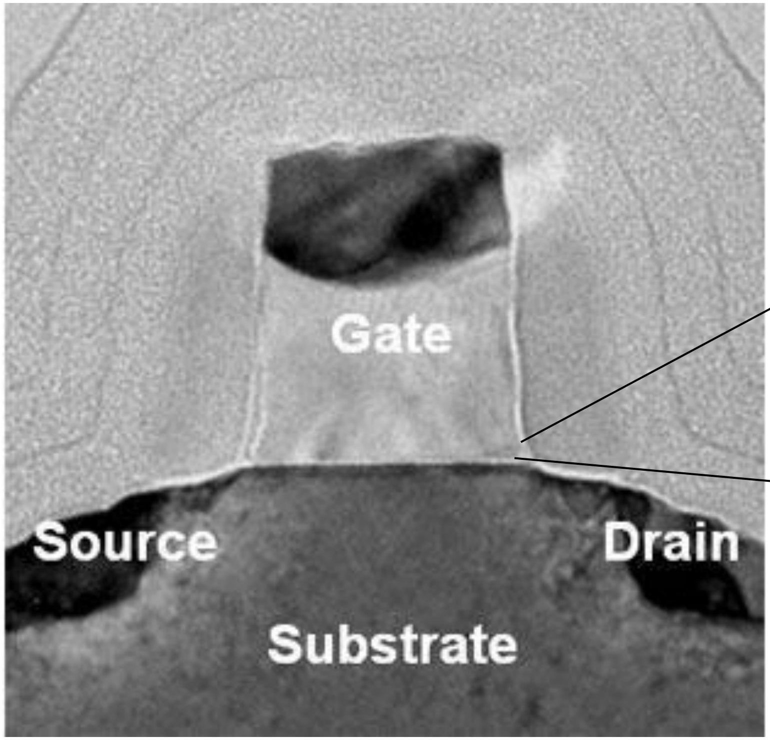
- 5000 nanometer process
- 1.023 MHz (CPU)
- 10,000s of transistors
- 160 x 200 x 16 color display
- $1300 dollars at release (adjusted for inflation)

- 45 nanometer process
- 1,000 MHz
- 100,000,000 transistors
- 320 x 480 x 262,144 color display
- $600 dollars at release

CPU Transistor Counts 1971-2008 & Moore's Law



Electron Microscope view of MOS Transistor



Insulating Layer (gate oxide) now just 1.2 nm thick

For reference:
  Human hair: 100,000 nm
  Silicon atom: 0.1 nm

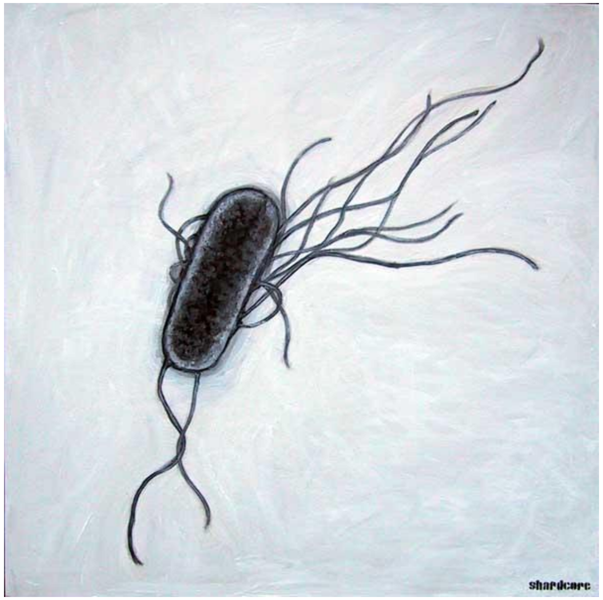
35 nm wide

In 10 years, we **will** hit a wall.

Courtesy: Tom's Hardware, June 11 2006 (65 nm process)

There's (still) Plenty of Room at the Bottom

- "There's more than one way to build a nanoscale information processing unit" – Folklore
- *E coli* is a 2000 nm by 500 nm device by area (in 3D, 500 nm tall)



  - Self-replicating, self-powered system
  - 1 million interconnected subdevices of 4000 types
  - Stores 1 megabyte of genomic data
  - Humans are capable of building only a 10 bit SRAM in the same area

Painting of E. Coli courtesy of shardcore.org

Even if we switch from MOS transistors…

- Integrated Circuits will be an important technology for a long time
- Designing and building these circuits requires knowledge in many fields
  - **Circuit analysis**
  - Semiconductor physics
  - Chemistry
  - Computer microarchitecture
  - Signal processing
  - And many many more…

EE 40 Course Overview

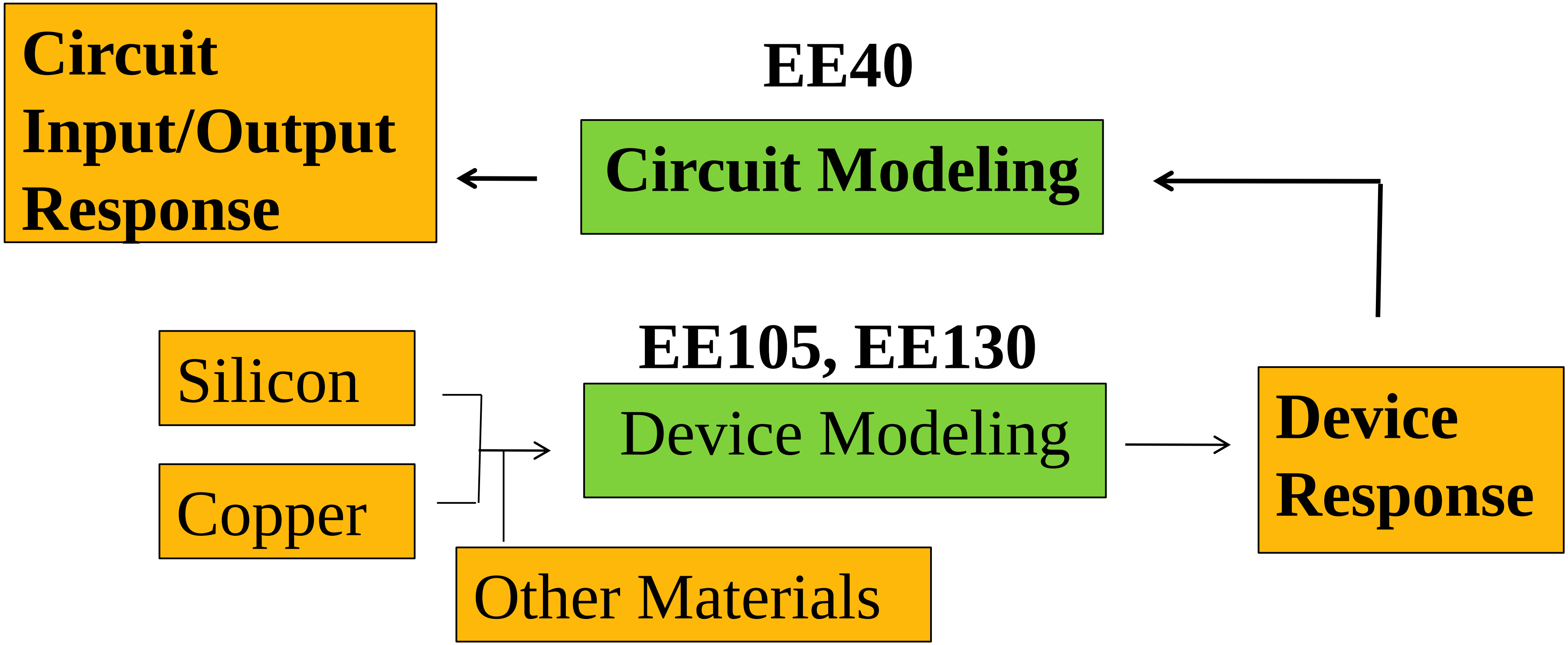
EECS 40:

- **One of five EECS core courses (with 20, 61A, 61B, and 61C)**
  - introduces "hardware" side of EECS
  - prerequisite for EE105, EE130, EE141, EE150
- **Prerequisites: Math 1B,** Physics 7B

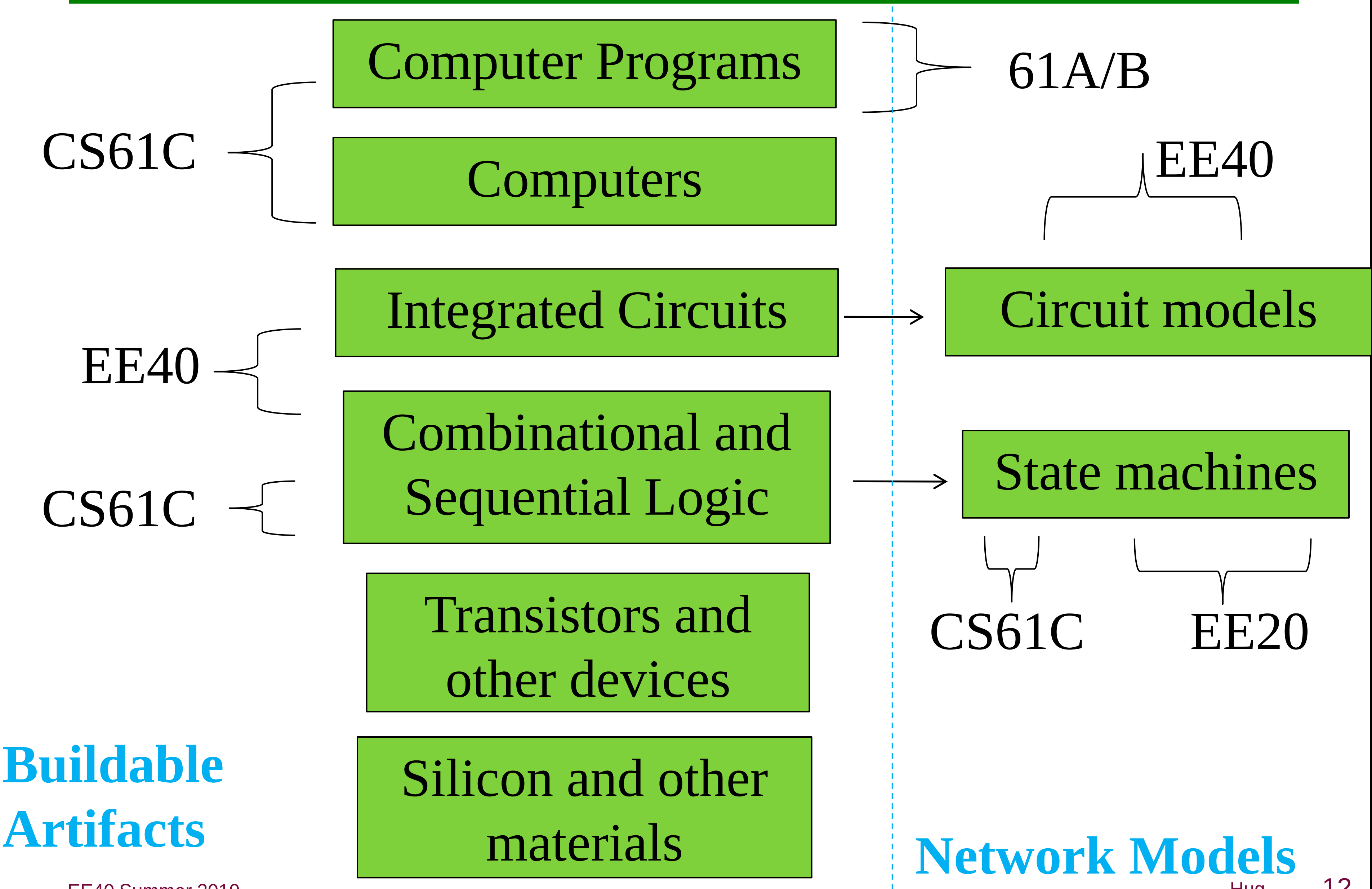
Course content:

- **Electronic circuits**
- **Some very basic semiconductor physics**
- **Integrated-circuit devices and technology**

EE40


Circuit Input/Output Response
EE40
Circuit Modeling
EE105, EE130
Silicon
Copper
Device Modeling
Device Response
Other Materials

Core EECS Courses (Computer Centric View)



Course Logistics

Important Dates

- Two or three in-class midterms
  - July 9th (18 days from now)
  - July 28th
  - August 11th (if you guys vote to do this)
- One comprehensive final
  - August 13th
- July 2 – must be registered for course
- June 25th – last day to drop for a refund
- July 30th – last day to drop for no refund

Grades

- Reading Assignments (5%)
- HW (20%)
  - Lowest HW dropped
  - One late homework allowed
- Midterm and Final (20%, 20%, 20%)
  - If we do 3 midterms, lowest dropped
- Labs (15%)
  - Six labs
  - Two lab projects
    - 2nd project is open ended, get started early if you want to do something crazy

Reading Assignments

- Reading assignments due before class
  - Easy problems to make sure you got at least something out of the reading
  - Credit/No Credit grading
  - No late submissions allowed
  - Lowest two dropped
  - Submit on bspace (bspace.berkeley.edu)

Homeworks

- **Homeworks due on either Tuesdays or Fridays**
- Must be in the HW box, 240 Cory by 5 PM
- Problems graded on a 0,1,2,3 basis
  - You do not get 1 point for writing the problem down
- Will be returned in lecture
  - Also available during my office hours
- On the top page, right top corner, write your name (in the form: Last Name, First Name)
- Fine to discuss problems with others but **ALL WORK SHOULD BE YOUR OWN**

Homework Philosophy

- Homework is where the real learning happens, similar to practicing a musical instrument
- My homeworks are for a grade so that if you perform poorly on midterms, it is evidence of what you've accomplished outside of a testing environment
- Copying homework answers is tempting, but:
  - It is an unfair representation of your accomplishments
  - You will be unprepared for midterms

Labs

- Labs start NEXT week
- 2 labs per week, 3 hours each
- Labs
  - 50% on Prelab and 50% on Report
    - Do prelabs BEFORE the lab
  - **You must complete the prelab section before going to the lab.** The prelabs are checked by the GSIs at the beginning of each session. If prelabs are completed during the lab sessions, it is considered late and 50% will be deducted
- Lab reports are due exactly one week after your lab is completed
- Some make up labs will be scheduled

Discussion Sections and Office Hours

- Note that discussion section times have changed, now only one hour:
  - Tuesday: 1-2 PM
  - Friday: 2-3 PM
  - Held in 293 Cory

- Office Hours will be posted later today

Textbook and i>Clicker

- Our textbook is “Foundations of Analog and Digital Electronic Circuits”, 1st edition by Anant Agarwal and Jeffrey Lang

- Also required is an i>Clicker
  - For submitting answers in class
  - Available at ASUC bookstore or online
  - ASUC will buy them for $30 (as of last semester)
  - Will register them by serial # to your name online (details on website soon)

Lectures

- We have a 2 hour lecture
- Nobody on this earth is that entertaining
- End of each hour – peer instruction
  - Work on small problem in groups
  - Submit answer via **i>Clicker**
  - Go over problem
  - Take a break
- Attendance isn't required, but reading assignments for lecture ARE required
- Lectures will be posted online

i>Clicker Test

- Let’s test those i>Clickers
- Question: Does your i>Clicker work?

A. Yes

B. No

Course Website

- Course website is at http://www-inst.eecs.berkeley.edu/~ee40/su10/
- Homeworks, midterm solutions, labs, and anything else we want you to know will be posted there
- Bspace will be used for
  - Submitting reading assignments
  - Discussion board

HW0

- Mini-biography assignment
- Due Wednesday
- May submit either:
  - Online on bSpace (due at midnight)
  - In class (at beginning of class)

- Our HW0 is available on the web under our pictures

Study Groups

- Learning or working in a team works better than alone
  - Reduces chance that you get stuck on something minor
  - Helping someone else requires very deep well organized knowledge of a topic
    - You learn best by teaching
  - Provides a chance to learn how to solve problems more efficiently and with higher accuracy
  - Gives immediate feedback on how you stand on coursework comprehension

Study Groups

- In my obscenely difficult Graduate Probability and Statistics Class, we'd:
  - Start the homework early (like the day it came out), and attempt all of the problems alone.
  - Meet a day or two before it was due
    - Go over every homework problem
    - Discuss our approach to each
    - Different person led on each problem

- This is fine, but ALL WORK MUST BE YOUR OWN. Do not copy.

Extra Credit: EPA!

- Effort
  - Attending office hours, completing all assignments, turning in HW0
- Participation
  - Attending lecture and voting using i>Clickers
  - Asking great questions in discussion, lab, and lecture and making things generally more interactive
- Altruism
  - Helping others in lab or on the discussion board
- EPA! extra credit points have the potential to bump students up to the next grade level! (but actual EPA! scores are internal)

Course Problems…Cheating

- What is cheating?
  - Studying together in groups is encouraged.
  - Turned-in work must be *completely* your own.
  - Common examples of cheating: running out of time on a assignment and then copying an answer from a friend, taking homework from box and copying, asking to borrow a solution "just to take a look", copying an exam question, …
  - Both "giver" and "receiver" are equally culpable
- Cheating points: 0 EPA, negative points for that assignment / lab / exam (e.g., if it's worth 10 pts, you get -10) In most cases, F in the course.
- Every offense will be referred to the Office of Student Judicial Affairs.

www.eecs.berkeley.edu/Policies/acad.dis.shtml

About Me (Josh Hug)

- 6th year graduate student
- Research on Biological Systems
  - How *Bacillus subtilis* makes decisions
  - Math is the same as we'll use in this class
- One day, maybe a Teaching Professor
- My HW0 is available online!

My Goal as an Instructor

- To make your time in EE40 as fun and informative as I can
  - Make lectures interesting and timely
  - Bring out the beauty and make clear the usefulness of the material
  - Give secrets to getting good grades
- To get a 7.0 with HKN
  - This is my first class, be gentle
  - I'll need your feedback as much as possible

Friday Lunch

- Every Friday after class
- Email me at least a day in advance so that I am not overbooked

Teaching Staff

- GSI/TAs:
  - Onur Ergen
  - Cooper Levy
- Readers/Lab Assistants:
  - Jonathan Lin
  - Tony Dear

Topic 1

Fundamentals of Electronic Circuits

Topic 1

- Outline
  - **Electrical quantities**
    - **Charge, Current, Voltage, Power**
  - **The ideal basic circuit element**
  - **Circuit schematics**
  - **Sign conventions**
- Mostly a review of Physics 7B

Etymology

- The word electric is derived from the Greek elektron (Latin electrum) denoting amber.
- It was discovered in ancient times that when amber is rubbed it attracts feathers, dried leaves, etc.
- This is due to the amber becoming charged (discovered much later).
- These are the roots of our subject.

Common Sense

- If we take a AA battery and a paperclip and connect the two terminals, it heats up
- If we stick the same paperclip into the wall outlet and get it to actually stay there, it will heat up much more (and then melt)
- This heat is due to the flow of electrical **current** driven by the **voltage** provided by the source
  - As electrons bump into neighboring electrons, they get jostled around. This is exactly what heat is

Intuition Test and a break

- We decide to stick a piece of wire in a nearby electrical outlet to heat our room.
- We have a choice of many different thicknesses of wire to use. Assume that resistance scales inversely with diameter of the wire, i.e. R_{wire}=constant/diameter
- Assuming our wire won't melt, if we wish to maximize the amount of heat generated, which wire should we choose:

A. The thinnest wire **B. The thickest wire** **C. Some medium wire**

The Universe

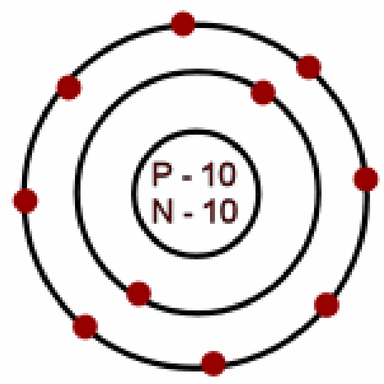
- Electric charges exert forces on other electric charges, according to Coulomb's Law:

$$F = k_e \frac{q_1 q_2}{d^2}$$

- The part of the universe we care about is made up of atoms composed of these charges
  – Negative charges (electrons) orbiting a positively charged nucleus in discrete (i.e. quantum) orbits

Atomic Structure

- Electrons are organized into orbitals, basically a nested set of shells
- If you rememeber high school chemistry:
  - Neon's electronic subshells: $1s^2 2s^2 2p^6$



- The existence of these shells plays a key role in conductivity. It is hard to give an electron to someone with no room to hold it.

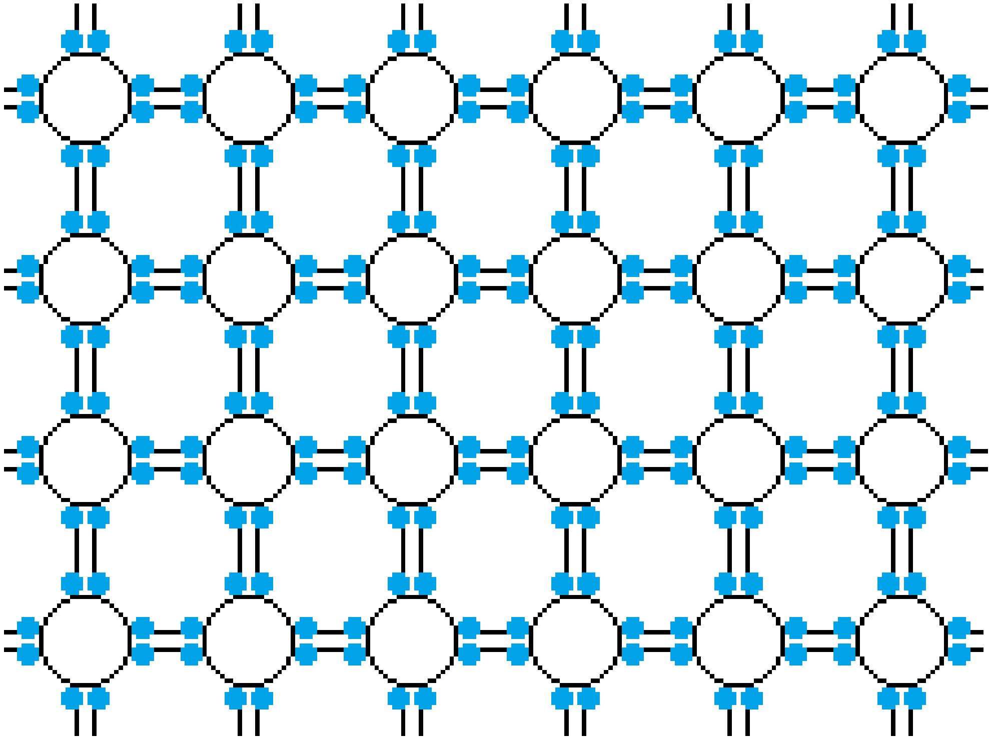
http://www.iq.poquoson.org/6sci/atoms/neonA.gif

Matter

- Atoms agglomerate into solids, liquids, and gases
- Typically, most objects in the world are neutrally charged
  - Exceptions: clouds in a thunderstorm, people on carpets in dry weather, rubbed amber, plates of a charged capacitor, *etc.*
- When there is an imbalance of charge, there are forces (Coulomb's Law)
  - – Static cling
  - – Current through a wire

Classification of Materials: Insulators

- Solids in which all electrons are tightly bound to atoms are **insulators**.
  - e.g. **Neon**: applying an electric field will tend to do little, because it is hard for an electron to move in to your neighbors valence shell.



CoM : Metals and Semiconductors

- Solids in which the outermost atomic electrons are free to move around are metals
  - Metals typically have ~1 “free electron” per atom
  - $\sim 5 \times 10^{22}$ free electrons per cubic cm
- Electrons in semiconductors are not tightly bound, nor are they free, but can be easily “promoted” to a free state

insulators	**semiconductors**	**metals**
Quartz, SiO_2	**Si, GaAs**	**Al, Cu**
poor conductors		excellent conductors

Abstraction

- Though a detailed quantum mechanical formulation would be the most accurate choice, it would be hard to use
- Thinking of 10^{23+} atoms composed of charged subatomic particles each with their own individual state is too much
- We'll instead lump large objects like a battery into more abstract pieces
- Likewise, we will treat current as a bulk flow of charges

Current

- **Electrical Current** is simply a measure of the net amount of positive charge that passes a plane in space per second in a reference direction
- For convenience, the base unit is 1 **Ampere**, which is $1.6x10^{19}$ charges/sec or 1 **Coulomb**/sec

Bissell Healthy Home Upright Vacuum Cleaner, Bagless, 100 Quintillion electrons/sec, 16N5
by Bissell
(57 customer reviews)

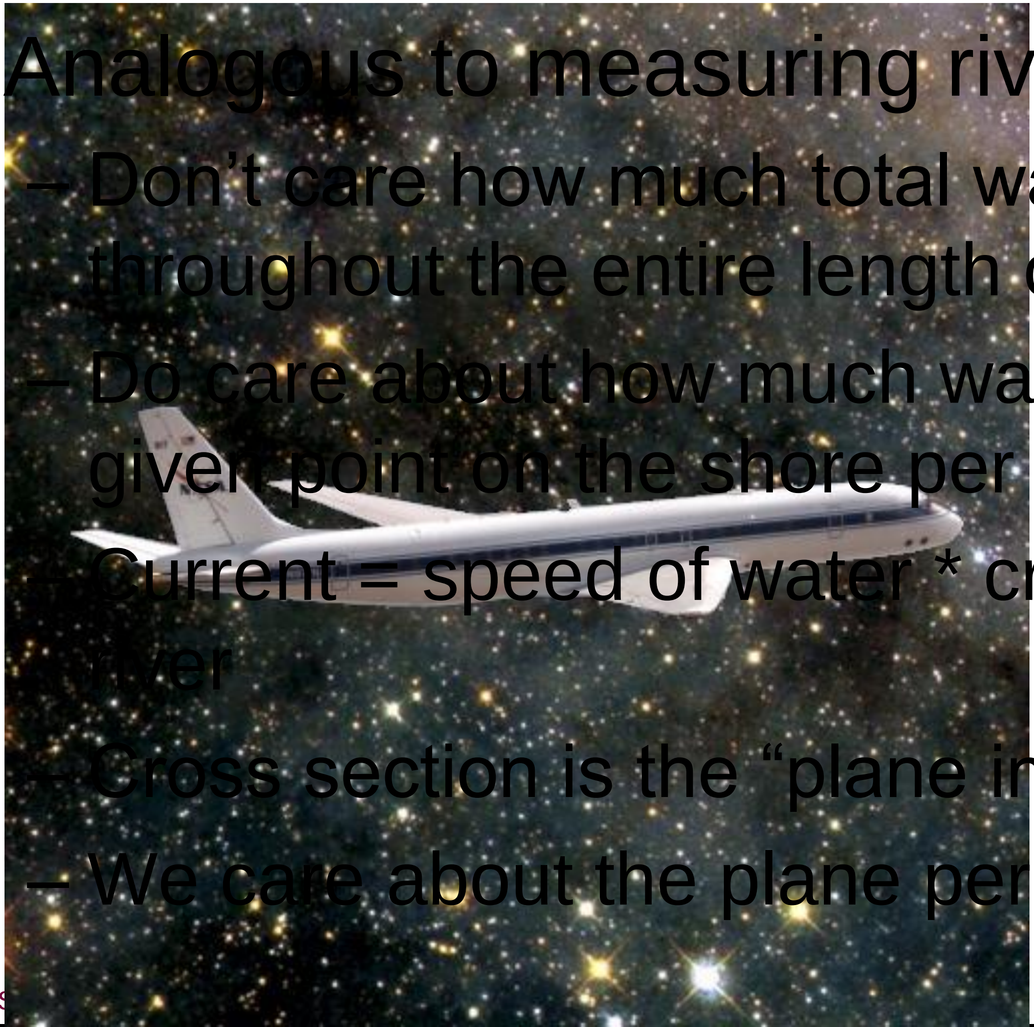
List Price: ~~$249.99~~
Price: $176.38 & this item ships for **FREE with Super Saver Shipping**. Details
You Save: $73.61 (29%)

In Stock.
Ships from and sold by **Amazon.com**.
Want it delivered Tuesday, June 22? Order it in the next 17 hours and 11 minutes, and choose **One-Day Shipping** at checkout. Details

21 new from $172.94

A Plane in Space?

- Net amount of positive charge passing a plane in space in a reference direction
- Analogous to measuring river flow
  - Don't care how much total water is moving throughout the entire length of a river
  - Do care about how much water is passing a given point on the shore per second
  - Current = speed of water * cross section of river
  - Cross section is the "plane in space"
  - We care about the plane perpendicular to flow



?

Electric Current Examples

1. 10^5 positively charged hydrogen ions (each with charge 1.6×10^{-19} C) pass the perpendicular plane in space to the right ($+x$ direction) every nanosecond. What is the current to the right?

$$10^5 \frac{ions}{nanosecond} \times \left(1.6 \times 1 \;\; 1.6 \times 10^{-5} \; Amps \; \frac{}{ion} \right. = 1.6 \times 10^{-5} \frac{Coulombs}{second} \; \frac{s}{\imath d}$$

2. 10^5 electrons (each with charge -1.6×10^{-19} C) pass the perpendicular plane in space to the right ($+x$ direction) every nanosecond. What is the current to the right?

Current is net positive charges to the right, so…

$$-1.6 \times 10^{-5} \; Amps$$

Electric Current Summary

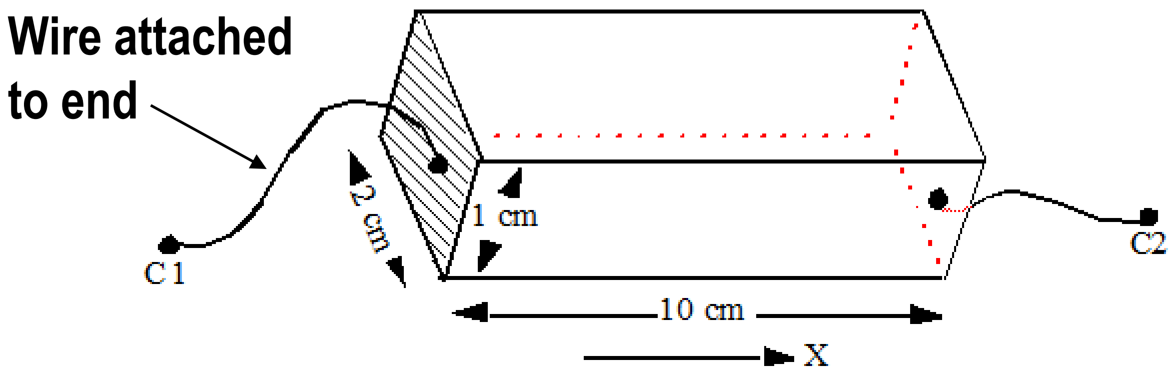
- **<u>Definition</u>:** Rate of positive charge flow in a reference direction
- **<u>Symbol</u>:** I
- **<u>Units</u>:** Ampere (A) = 1 Coulomb/second

- Simply the net amount of charge/second passing through a plane perpendicular to the direction of flow

Current Density

Definition: rate of positive charge flow per unit area
Symbol: J
Units: A / cm^2

Example 1:



Suppose we force a electron current of 1 A to flow from C1 to C2, what is the current density:

- Electron flow is in -x direction through 2cm^2 cross section:

-0.5 A/cm^2

Voltage

- The **voltage between two points** in space is simply the amount of energy (in Joules) that it would take to move 1 Coulomb of charge between those two points
- Example: There is a uniform electric field pulling electrons to the left at 9.8 Newtons/Coulomb. How much energy would it take to move this charge 2 meters to the right?

$$\mathbf{19.6\,Volts} = 9.8\frac{Newtons}{Coulomb} \times 2\,meters$$

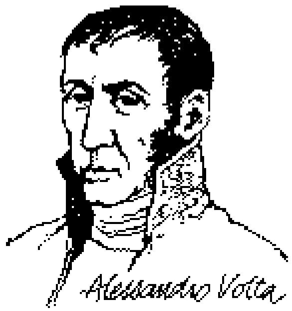
Analogy to Gravity

- Example: There is a uniform gravitational field pulling some matter downwards at 9.8 Newtons/kg. How much energy/kg would it take to move this matter 2 meters upwards?

$$\mathbf{19.6}\frac{\boldsymbol{Joules}}{\boldsymbol{kg}} = 9.8\frac{Newtons}{kg} \times 2\ meters$$

Electric Potential (Voltage)

- **Definition:** energy per unit charge
- **Symbol:** v
- **Units:** Joules/Coulomb ≡ Volts (V)

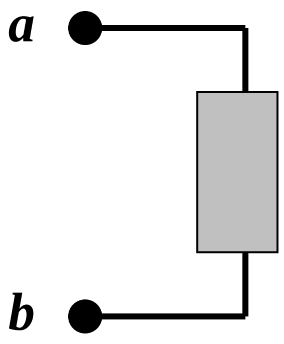


Alessandro Volta
(*1745–1827*)

$$v = dw/dq$$

where w = energy (in Joules), q = charge (in Coulombs)

Note: Potential is always referenced to some point.



Subscript convention:

$\boldsymbol{v_{ab}}$ means the potential at $\boldsymbol{a}$ minus the potential at $\boldsymbol{b}$.

$$\boldsymbol{v_{ab} \equiv v_a - v_b}$$

Electric Power

- **Definition:** transfer of energy per unit time
- **Symbol:** p
- **Units:** Joules per second ≡ Watts (W)

$$p = dw/dt = (dw/dq)(dq/dt) = vi$$

- **Concept:**

  As a positive charge q moves through a drop in voltage v, it loses potential energy

  - Voltage is Joules/Coulomb
  - Current is Coulombs/second
  - Power is the product of these

Summary

- So far:
  - Current: Number of positive charges per second passing a plane in a particular direction
  - Current density: Current per unit area
  - Voltage: Amount of energy per Coulomb to move a charge between two points
  - Power: Amount of energy per second
- Where do these quantities arise?
  - When we build networks of electrical components

Power Sources

- We want to get charges moving in a controlled fashion
  - Generate heat
  - Turn motors
  - Perform computation
  - Store entire corpus of written human work in easily transmittable format
- It is easier to build a source which provides an almost constant voltage as opposed to an almost constant current (more on this later)

Voltage Sources

- One of the fundamental devices in electrical engineering is the voltage source
  - Batteries
  - Generators
- Provide a consistent voltage difference between two points in space
- If a charge is at the "top" of the voltage, a force will try to move it towards the "bottom"

Voltage Sources

- Positive and negative charges will move in opposite directions given the same voltage
- "Positive" terminal of a voltage source
  - High potential for a positive charge
  - Low potential for a negative charge

Our First Circuit

- Imagine that we have an ideal voltage source connected to a piece of metal. What happens?
  - Electrons at the negative terminal travel towards the positive terminal
  - These electrons will encounter some resistance as they travel generating heat
  - The current of the electrons will be a function of this resistance and the original voltage

Ohm's Law

- Ohm* discovered in 1825 that for many materials, voltage and current are related by a simple linear relationship: V=IR
- Here the "resistance" is a bulk property of the object connecting the two terminals of a voltage source and is empirically derived
  - Measured in Ohms
- Any material which obeys Ohm's Law is called a "resistor"

*: Cavendish was first in 1781, but didn't publish. Take note.

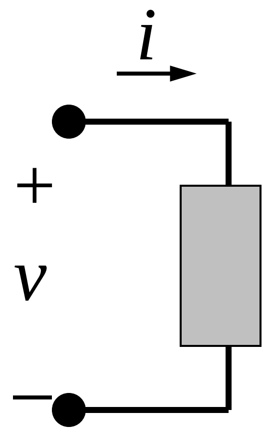
Ohm's Law

- Ohm's law doesn't always work
- Consider your wall outlet with terminals connected by a gaseous mixture of mostly nitrogen and oxygen
  - There is no current flow
  - With a high enough voltage, called the breakdown voltage, current will eventually flow (via a spark, a.k.a. lightning)
  - Such phenomena are beyond the scope of this course

Circuit Schematics

- Ohm's law paved the way for simple circuit schematics
- We can model circuits as a series of interconnected discrete components or **ideal basic circuit elements**
  - For now, each component can be characterized with a single physical parameter

The Ideal Basic Circuit Element



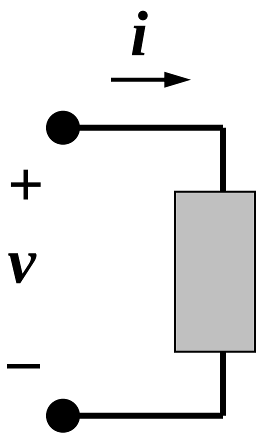
- Polarity reference for voltage can be indicated by plus and minus signs
- Reference direction for the current is indicated by an arrow

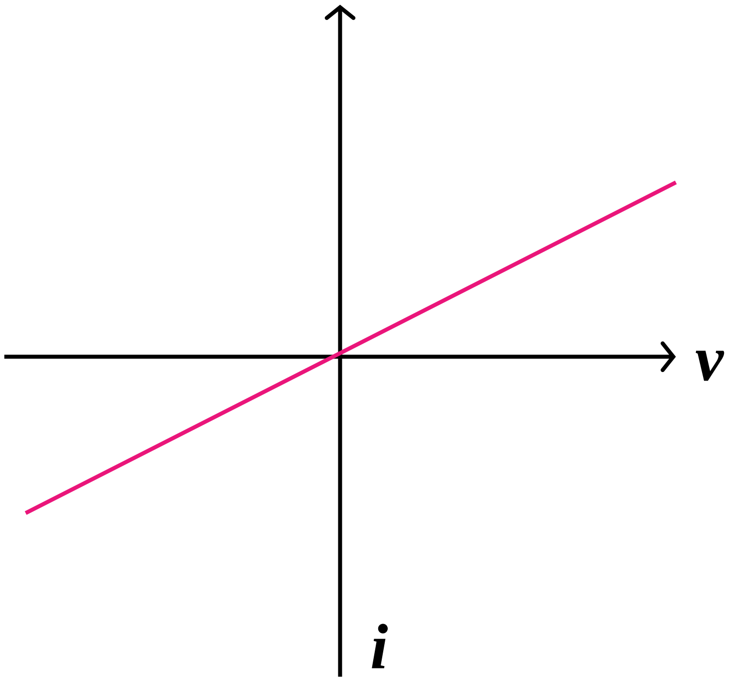
Attributes:

- Two terminals (points of connection)
- Device model gives us current/voltage relationship (I-V Characteristic)
- Cannot be subdivided into other elements

Example Circuit Element: Resistor

- **Resistor:** Circuit element where the voltage across the element is linearly proportional to the amount of current flowing through the device



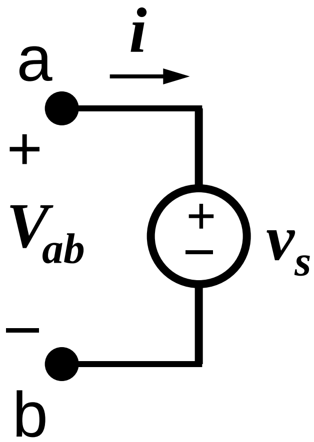


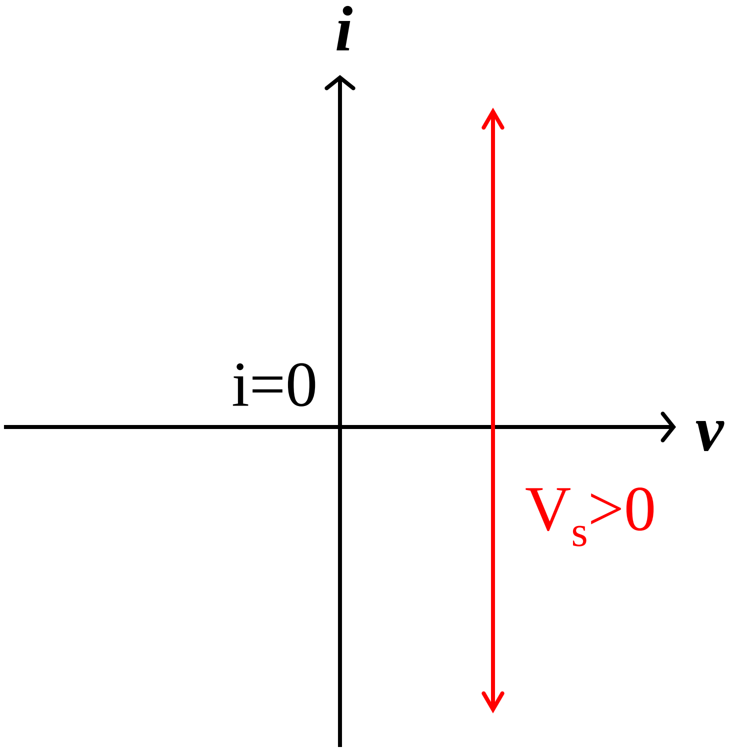
The slope must be positive and the characteristic must go through the origin.

Example Circuit Element: Voltage Source

- **Voltage Source:** Circuit element that maintains a prescribed voltage across its terminals, **regardless of the current flowing in those terminals**
  – Voltage is known, but current is determined by the circuit to which the source is connected
  – A battery can be approximated by a voltage source

I-V Characteristic of Ideal Voltage Source





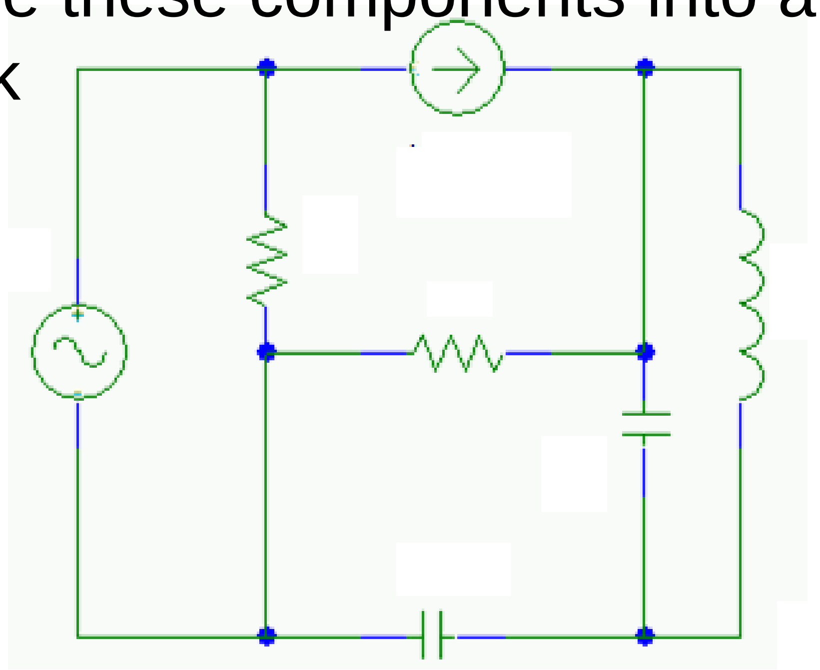
- Voltage is known, but current is determined by the circuit to which the source is connected

Circuit Schematics

- Combinations of ideal basic circuit elements
- A (high resistance) **paperclip** connecting the terminals of a 10 volt battery can be schematically represented as shown below

Larger Circuit Schematics

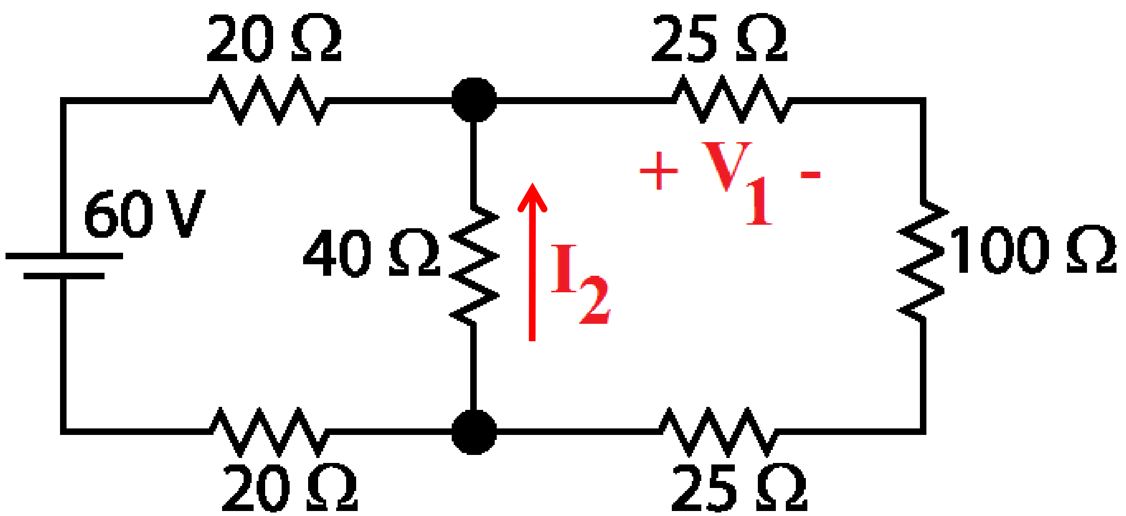
- We can compose these components into an arbitrary network



- For much of the semester we will discuss how to convert these networks into a system of algebraic (and later differential) equations
- The solution will give us the current and voltage between any two terminals in an arbitrary network

Example Problem Structure

- Find the voltage V_1 and current I_2



- Note that the problem statement assumes a certain reference direction for currents and voltages
- If you find that the reference direction is wrong, just note your answer as negative

Reference Example

- Find the current I_1

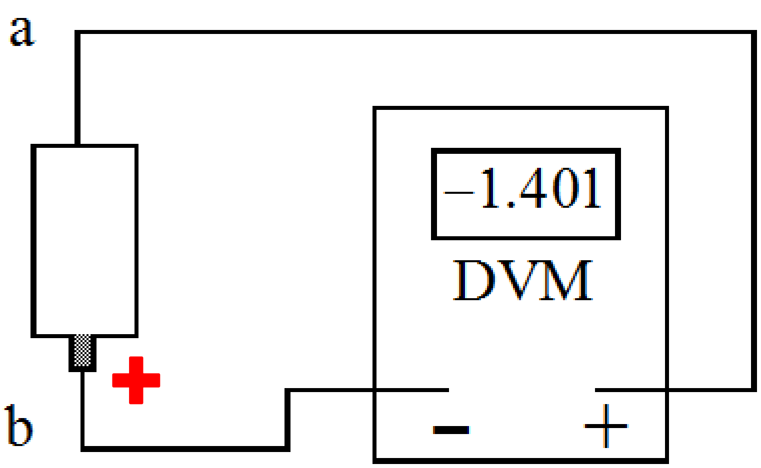
- Magnitude of the current is obviously 10V/100Ω or 0.1 Amps.
- Current flows from positive to negative, so "reference" current is wrong. Answer is -0.1 Amps

Reference Directions and Sign Conventions

- The minus sign is just shorthand for "it's going the other way than the one you asked for"
- Like asking "how fast is your plane moving in the direction of New York?" when you're flying away from New York
  - Could say "500 mph, but the other direction"
  - Or just "minus 500 mph"
- If you get confused on sign conventions at any point in the course, just step back and think about what is reasonable

Sign Convention Example

Suppose you have an unlabelled battery and you measure its voltage with a digital voltmeter (DVM). It will tell you the **magnitude and sign** of the voltage.



With this circuit, you are measuring v_{ab}.

The DVM indicates –1.401, so v_a is lower than v_b by 1.401 V.

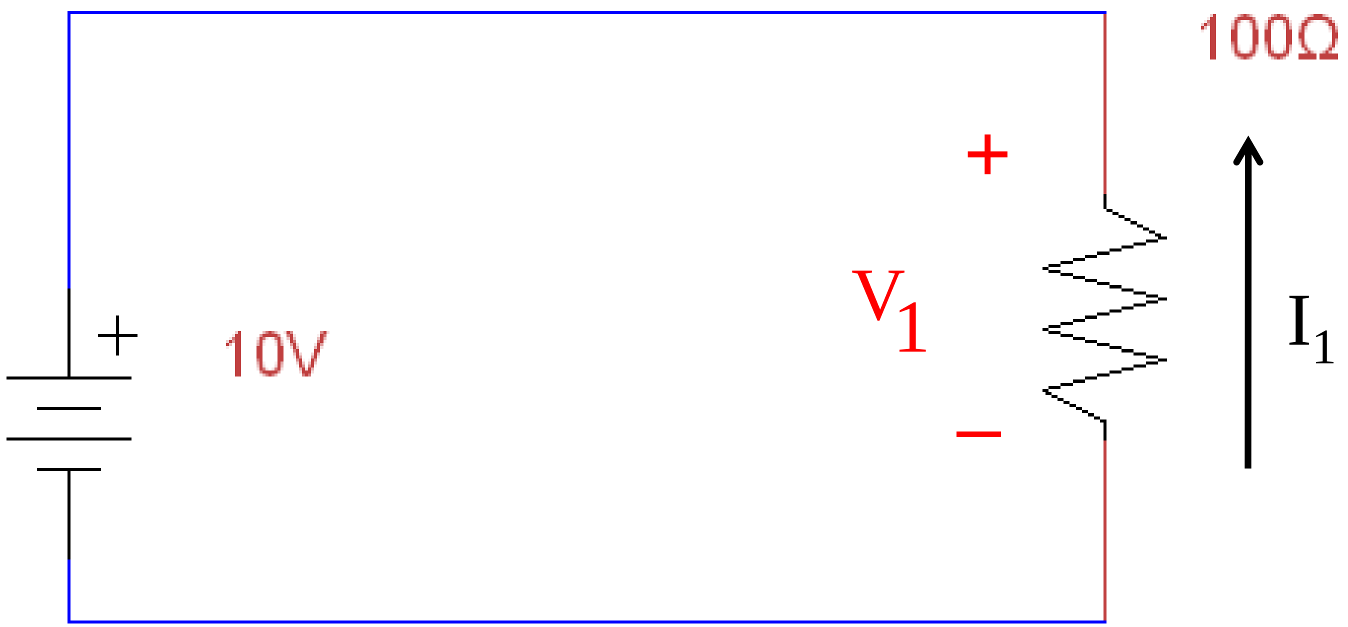
Which is the positive battery terminal?

Sign Convention for Power

- If $P > 0$ for a circuit element
  - Consuming power (as heat, light, motion, etc)
- If $P < 0$ for a circuit element
  - Providing power
- Resistors always consume power
- Voltage sources may consume or provide power

Sign Convention for Power

- Remember earlier that we said P=VI
- This can be problematic depending on the chosen reference directions

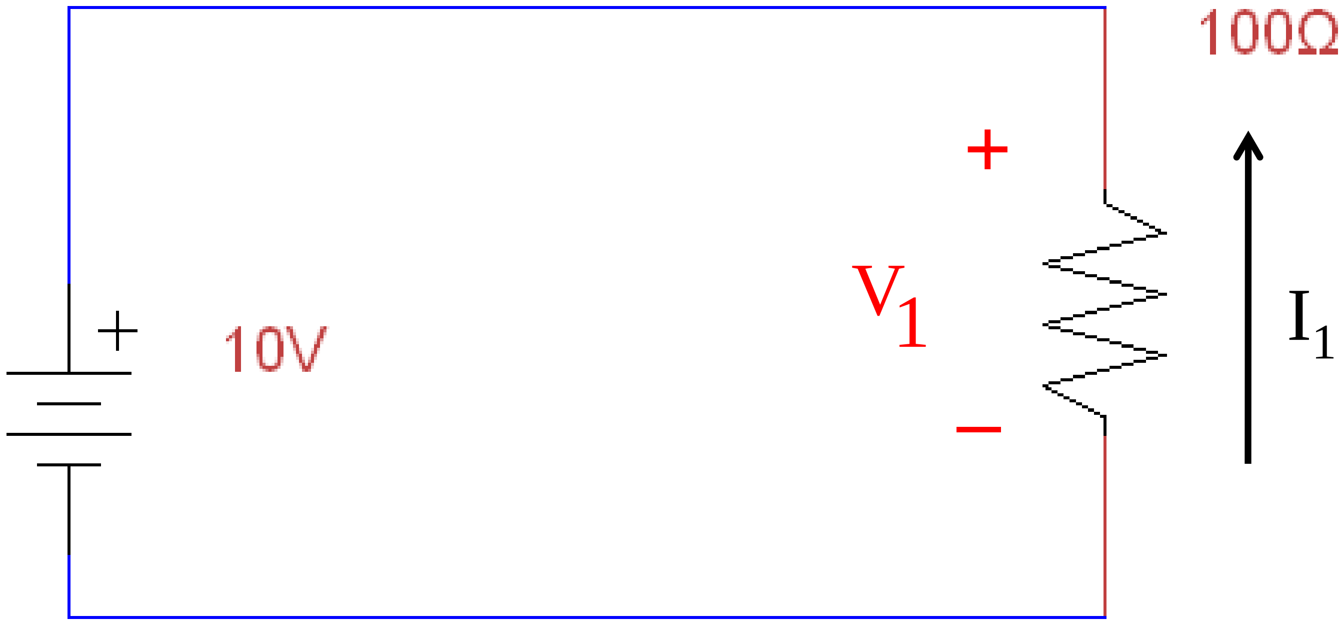


P=VI=10 V * (-0.1 Amps) = -1 Watt

Resistor providing power??

Sign Convention for Power

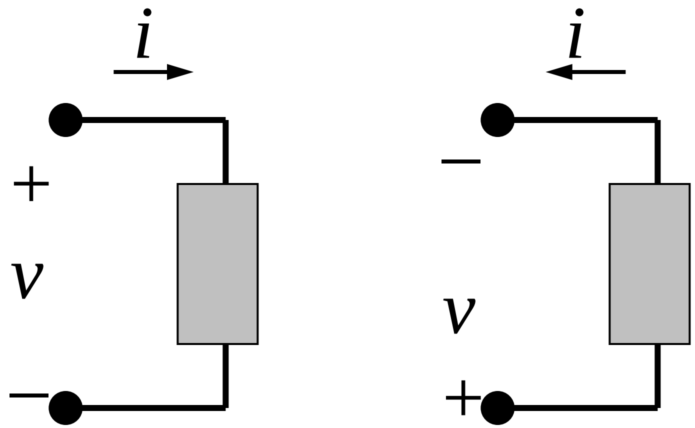
- We'll have to revise P=VI to take into account this reference direction problem



Sign Convention for Power

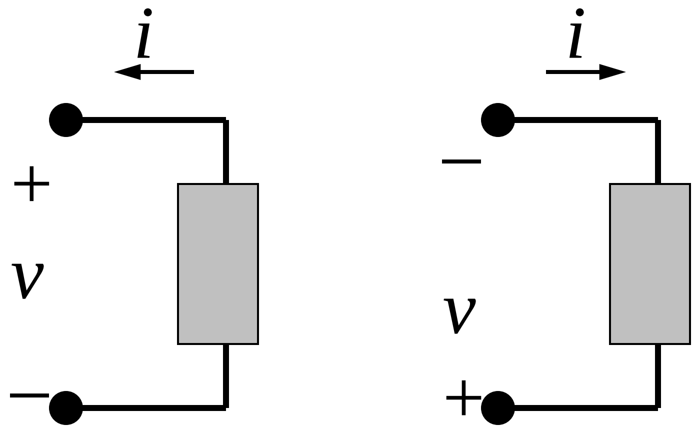
Passive sign convention

$$p = vi$$



Current from + to –

$$p = -vi$$

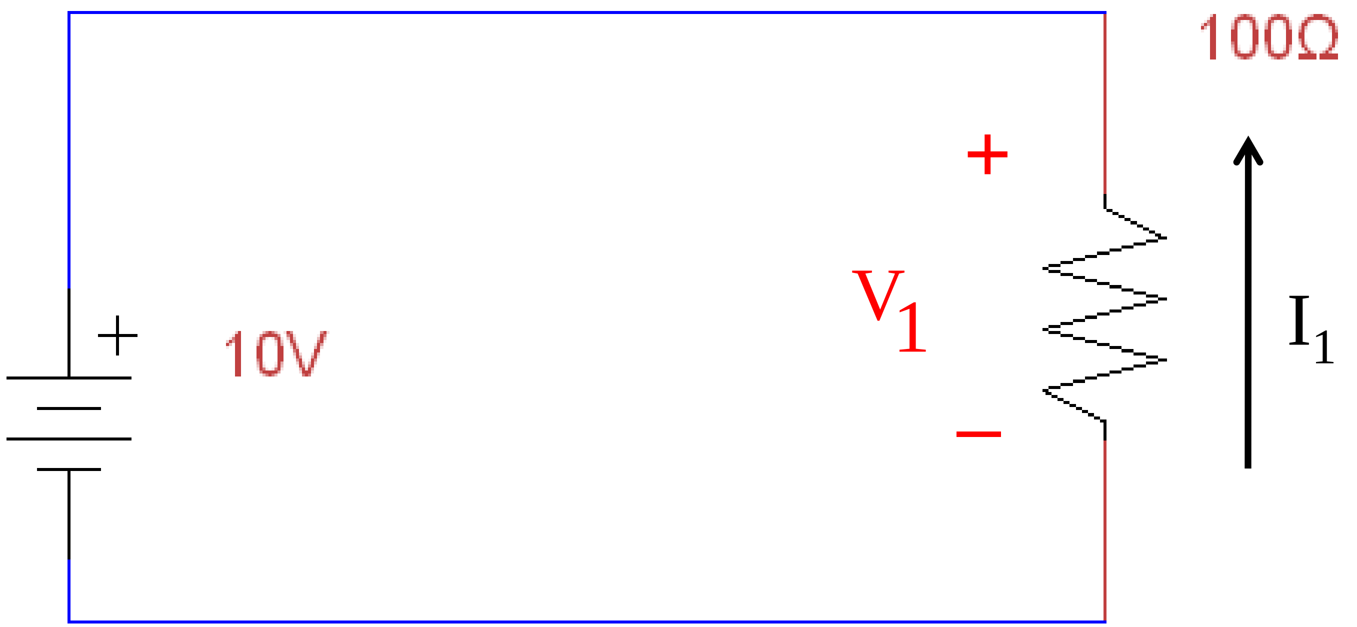


Current from – to +

- **If $p > 0$, power is being delivered to the box.**
- **If $p < 0$, power is being extracted from the box.**

Sign Convention for Power

- For this circuit, since reference current is in the opposite direction of reference voltage in the resistor, then P=-VI



P=VI=-10 V * (-0.1 Amps) = **1 Watt**

All is well

Summary

- ***Current*** = rate of charge flow
- ***Voltage*** = energy per unit charge created by charge separation
- ***Power*** = energy per unit time
- ***Ideal Basic Circuit Element***
  - 2-terminal component that cannot be sub-divided
  - Described mathematically in terms of its terminal voltage and current
- ***Circuit Schematics***
  - Networks of ideal basic circuit elements
  - Equivalent to a set of algebraic equations
  - Solution provides voltage and current through all elements of the circuit

iClickers Once More

- We decide to stick a piece of wire in a nearby electrical outlet to heat our room.
- We have a choice of many different thicknesses of wire to use. Assume that resistance scales inversely with diameter of the wire, i.e. R_{wire}=constant/diameter
- Assuming our wire won't melt, if we wish to maximize the amount of heat generated, which wire should we choose:

A. The thinnest wire **B. The thickest wire** **C. Some medium wire**

Acknowledgements

- Dan Garcia, Babak Ayazifar, Mike Clancy for help in CS302 (a course in course design)
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  - Tsu Jae King
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  - Octavian Florescu
  - Brian Gawalt
  - Bernhard Boser
- Labs
  - Bernhard Boser

Extra Slides

- Extra slides you're responsible for knowing about, but which I won't talk about in class for lack of time

EE40 Content (Detailed Version)

- Fundamental Circuit Concepts and Analysis Techniques
  - Networks of power sources and resistors
  - Op-amps
  - Signal amplification
  - Conversion of circuit schematics into algebraic equations
- Circuits with Energy Storage Elements
  - Capacitors
  - Inductors
  - Filtering
  - Conversion of circuit schematics into differential equations
- Semiconductors and Integrated Circuits
  - Basic semiconductor devices
  - Diodes
  - Transistors
  - Logic gates
- Textbook
  - Foundation of Analog and Digital Electronic Circuits, Anant Agarwal and Jeffrey Lang, Morgan Kaufman, 1st Edition

Final Grade Distribution – subject to change before first midterm

- Grading: 800 pts total
  - 120pts = 15% Labs
  - 160pts = 20% Homework
  - 320pts = 40% Two midterms (each 20%)
  - 160 pts= 20% Final
  - 40 pts = 5% Reading Assignments
    - \+ Extra credit for EPA. What's EPA?
- Grade distributions
  - Pseudo-Absolute Scale
  - Perfect score is 1000 points. 25-60-25 for A+, A, A-
  - Similar for Bs and Cs (110 pts per letter-grade)
  - C+, C, C-, D, F (No D+ or D- distinction)
  - Exception: No F will be given if all but one hw and labs are completed and all exams taken
  - We'll "ooch" grades up but never down

Weekly Calendar

<table>
<tr><th></th><th>Monday</th><th colspan="2">Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>8:00-9:00</td><td></td><td colspan="2" rowspan="3">Lab 140 Cory</td><td rowspan="3">Lab 140 Cory</td><td></td><td></td></tr>
<tr><td>9:00-10:00</td><td></td><td></td><td></td></tr>
<tr><td>10:00-11:00</td><td></td><td></td><td></td></tr>
<tr><td>11:00-12:00</td><td>Cooper OH</td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>12:00-1:00</td><td rowspan="2">Lecture 60 Evans</td><td colspan="2"></td><td rowspan="2">Lecture 60 Evans</td><td>Cooper OH</td><td rowspan="2">Lecture 60 Evans</td></tr>
<tr><td>1:00-2:00</td><td colspan="2">Discussion</td><td></td></tr>
<tr><td>2:00-3:00</td><td></td><td rowspan="3">Lab 140 Cory</td><td rowspan="3">HW Due 5PM in 240 Cory Drop Box</td><td rowspan="3">Lab 140 Cory</td><td></td><td>Discussion</td></tr>
<tr><td>3:00-4:00</td><td></td><td></td><td></td></tr>
<tr><td>4:00-5:00</td><td></td><td></td><td>HW Due 5PM in 240 Cory Drop Box</td></tr>
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Core EE Courses