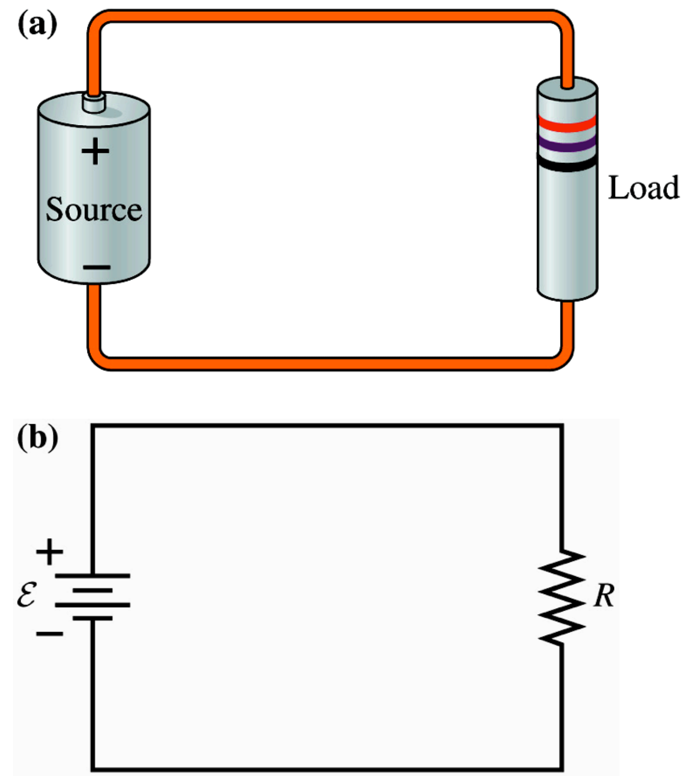
# Physics 115
## General Physics II




## Session 23
# Series and parallel R
# Real Batteries
# Meters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# Lecture Schedule

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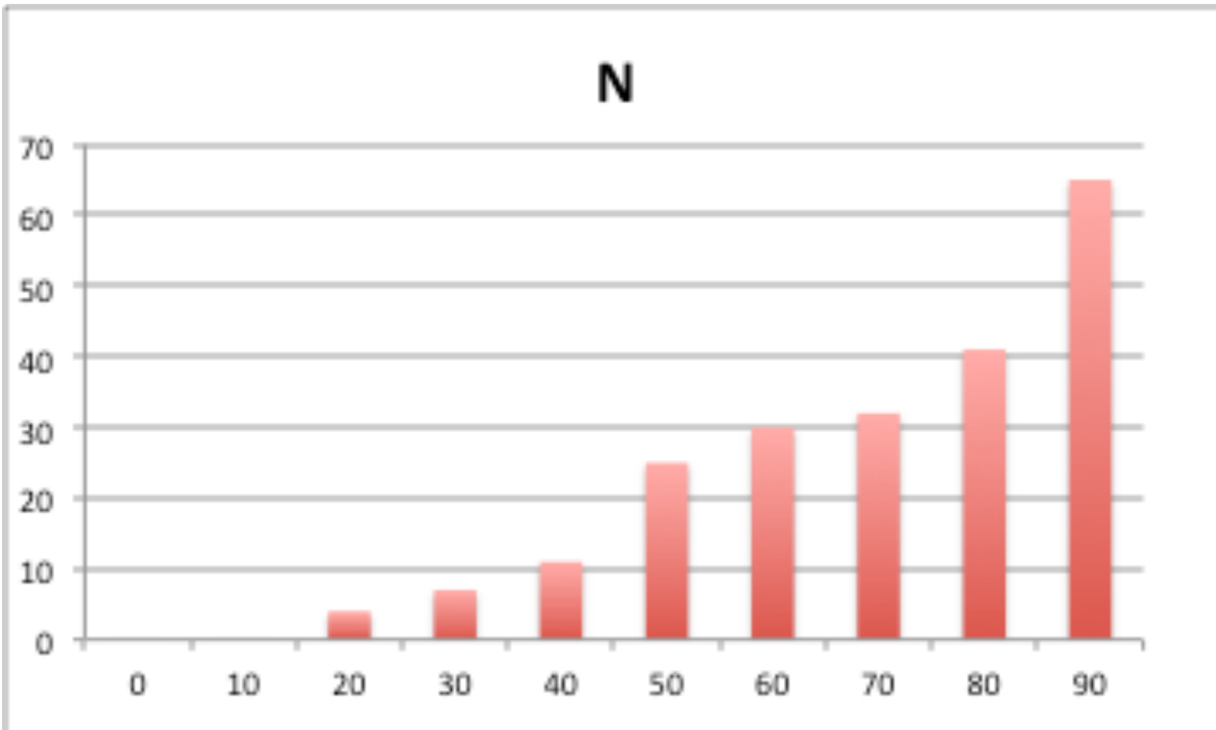
|---|---|---|---|---|
| **12-May** | Mon | 23 | DC Circuits & Meters | 21.5-21.8 |
| **13-May** | Tues | 24 | DC Circuits | 21.5-21.8 |
| **15-May** | Thurs | 25 | RC circuits | 21.6-21.7 |
| **16-May** | Fri | 26 | Circuits - Neurons | |
| **19-May** | Mon | 27 | Magnetism | 22.1 |
| **20-May** | Tues | 28 | Magnetic Force | 22.2-22.5 |
| **22-May** | Thurs | 29 | Magnetic Fields | 22.6-22.7 |
| **22-May** | Fri | 30 | Induced EMF, Applications | 23.1-23.3 |
| **26-May** | ***holiday*** | | NO CLASS | |
| **27-May** | Tues | 31 | Energy, RL circuits | 23.4-23.8 |
| **29-May** | Thurs | 32 | Transformer | 23.9-23.10 |
| **30-May** | **Fri** | | **EXAM 3 - Chapters 21,22,23** | |
| **2-Jun** | Mon | 33 | AC circuits | 24.1-24.3 |
| **3-Jun** | Tues | 34 | AC circuits | 24.4-24.5 |
| **5-Jun** | Thurs | 35 | Resonance, Applications | 24.6 |
| **6-Jun** | Fri | 36 | Last class - review | |
| **June 9** | **FINAL EXAM** | | **2:30-4:20 p.m.** | **Comprehensive** |
| | Mon | | **Monday, June 9, 2014** | |

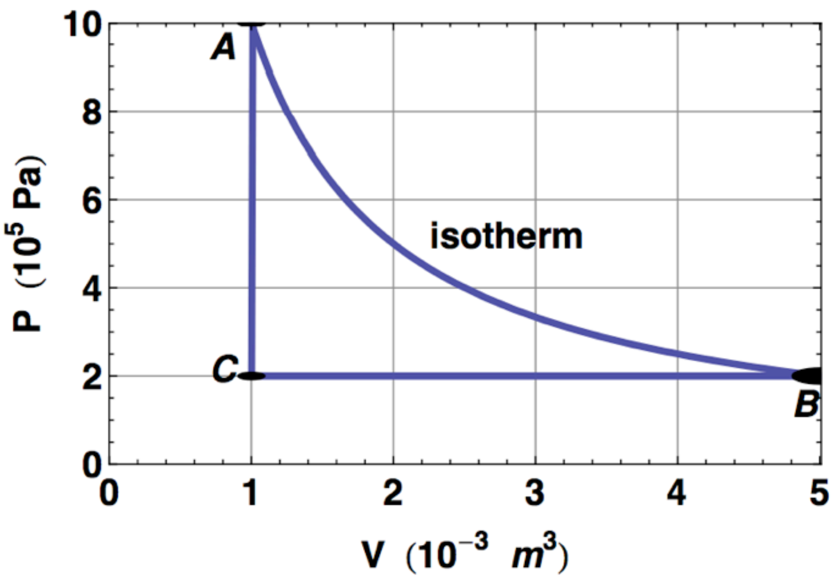
Today

# Announcements

- Exam 2 results (posted on WebAssign and Catalyst Gradebook)
  - Average = 76, standard deviation = 19



Questions are worth points shown




For questions 1-5: Working fluid for the P-V diagram above is an ideal monatomic gas.
For this system Nk = 2 SI units. PV = NkT
The area under the Isotherm between V = 1 and V = 5 $10^{-3}$ $m^3$ is approx. 1600 J (or N-m).
Temperatures are: $T_A$, $T_B$, $T_C$

1. (8 pts.) What is the temperature, $T_A$ (K) at point A?

A) 200

B) 100

C) 400

D) 500

E) 1000

**Ans: D. T=PV/Nk=(106Pa)(10-3m3)/2=500K**

2. (4 pts.) What is the temperature, $T_B$ at point B?

A) $T_A$

B) $T_A$ /2

C) $T_A$ /10

D) $T_A$ /5

E $T_A$ /2.5

**Ans: A. Isothermal connects A and B**

3. (6 pts) During the process A to B is work (WAB) done by the gas or on the gas?

A) By

B) On

C) No work is done

**Ans: A. Gas is expanding, work is done BY gas**

4. (6 pts) During the process A to B,, does heat ($Q_{AB}$) flow into the gas or out of the gas?

A. Into

B. Out of

C. No heat flow

**Ans: A. Work is done BY gas, so must add heat to keep U (~T) constant.**

5. (6 pts) During the process B to C, is work ($W_{BC}$) done by the gas or on the gas?

A. By

B. On

C. No work done

**Ans: B. Compression at constant P, so work done ON gas = area under B-C curve**

6. What is the efficiency of a heat engine that exhausts 1200 J of heat in the process of doing 250 J of work ?

A. 75 %
B. 33 %
C. 47 %
D. 66 %
E. 17 %

**Ans: E. $Q_H = Q_C + W = 1200J + 250J$; $\varepsilon = 1 - (Q_C / Q_H) = 1 - (1200J/1450J) = 0.17$**

7. With the pressure held constant at 170 kPa, 50 mol of an ideal monatomic gas expands from an initial volume of 1.5 $m^3$ to a final volume of 2.9 $m^3$ . How much work was done by the gas during the expansion?

A. 189 kJ
B. 200
C. 67
D. 238
E. 100

**Ans: D. $W = P\Delta V = 170kPa\ (2.9 - 1.5\ m^3) = 238\ kJ$**

8. An air conditioner which is an ideal Carnot engine operates between an indoor temperature of 20°C and an outdoor temperature of 39°C. How much energy (work) must it provide to remove 2000 J of heat from the inside of the house?

A) 105 J

B) 130 J

C) 780 J

D) 520 J

E) 340 J

**Ans: B. Carnot efficiency =(1- *Tc*/ *T*h) =(1- *Q*c/ *Q*h)→ *Q*h= *Q*c(*T*h/ *T*c ) =2000(312/293)=2129.7J so require W= *Q*h – *Q*c =129.7 J**

9. Find the change in Entropy when 1 kg of water is boiled away to steam .
(both water and steam are at 100 °C )

A. 9.71 kJ/Kelvin
B. 6.06
C. 1.94
D. 5.62
E. 4.56

**Ans: B. $\Delta Q = mL = 1kg\ (2.26x10^6\ J/kg)$; $\Delta S = \Delta Q/T = 2.26x10^6\ J\ /\ 373K = 6.06kJ/K$**

10. What is the magnitude of the electric field produced at a distance of 520 m by a charge of 7 Coulombs ?

A. 0.38 Megavolts/meter
B. 1.73
C. 0.23
D. 1.94
E. 6.37

**Ans: C. $E = k\ Q/\ R^2 = (8.99\ x\ 10^9\ N.m^2/C^2)(7C)/(520\ m)^2 = 0.233\ MV/m$**

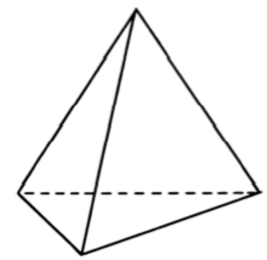
11. A box in the form of a Tetrahedron contains electric charge. The electric fluxes through the four sides of the box are as follows :

Flux1 = – 113 N. $m^2$/C ;

Flux2 = + 144 N. $m^2$/C;

Flux3 = + 26 N. $m^2$/C;

Flux4 = –12 N. $m^2$/C



Find the electric charge inside this box.

A. 0.398 nano Coulombs
B. 0.144
C. 0.74
D. 0.796
E. – 0.74

**Ans: A. $\Sigma\Phi$=45 N. $m^2$/C = $Q/\varepsilon_0$ ; Q=45 N. $m^2$/C (8.85 x $10^{-12}$ $C^2$ /N.$m^2$ )=0.398x$10^{-9}$ C**

For questions 12-13: An isolated parallel-plate capacitor has plates with an area of 0.017 $m^2$ and separation of 0.87 mm. Initially, the space between the plates is filled with a dielectric whose dielectric constant is 2.0.

12. What is the potential difference between the plates when the charge on the capacitor plates is $\pm$ 4.7 μC?

A) 13.6 kV

B) 27.2 kV

C) 54.4 kV

D) none of the above

**Ans: A**

$$C = \kappa\left(\varepsilon_0 A / d\right)$$
$$= 2\left(8.85\times10^{-12}\,\text{F/m}\right)\left(0.017\ \text{m}^2\ \right)/\,0.00087\text{m}$$
$$= 344\ \text{pF}$$
$$V = Q/C = \left(4.7\times10^{-6}\text{C}\right)/\left(344\times10^{-12}F\right) = 13.6kV$$

13. (4 pts.) Would your previous answer increase, decrease, or stay the same, if we remove the dielectric material, leaving the gap empty space (so, the dielectric constant is reduced to 1.0), all else staying the same?

A) stay the same

B) increase

C) decrease

**Ans: B. increase, because V is inversely proportional to κ: V =Q/C=Q/(κC0 ).**

14. Find the electric energy density between the plates of a 1.0 F parallel plate capacitor. The potential difference between the plates is 100 V and the plate separation is 1 mm . There is a vacuum between the plates.

A. 0.067 $J/m^3$
B. 0.172
C. 0.057
D. 0.044
E. 0.095

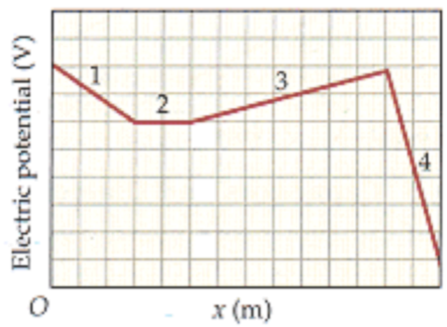
**Ans: D. $-E=\Delta V/\Delta s = (100V/0.001m) = 100kV/m$; $u = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}(8.85\times10^{-12})(10^5)^2\ J/m^3$**

15. An electron accelerates through a potential difference of 3000 V from rest . Find its final velocity .

A. 0.42 ( $\times 10^8$ m/s )
B. 0.32
C. 1.3
D. 0.76
E. 0.15

**Ans: B. $KE=\Delta U$; $\frac{1}{2}mv^2 = q\Delta V$; $v^2 = 2q\Delta V/m$**
**$v^2 = 2(1.6\times10^{-19}\ C)3000V/(9.11\times10^{-31}kg) = 1054\times10^{12}$; $v = 32\times10^6$ m/s**

For questions 16 -18: As a positive test charge moves along the $x$ axis from $x = 0$ to $x =$ 1.4 m, the electric potential it experiences is shown in the figure, below. (The horizontal axis is marked in increments of 0.1 m and the vertical axis is marked in increments of 0.5 V.)




16. (4 pts.) For which part of its path is the electrostatic force on the charge zero?
   A. segment 1
   B. segment 2
   C. segment 3
   D. segment 4
   E. none of the above

**Ans: B (E=0=slope of plot; slope=0 for segment 2)**

17. (4 pts.) For which part of its path does the electrostatic force point in the –x direction?
   A. segment 1
   B. segment 2
   C. segment 3
   D. segment 4
   E. none of the above

**Ans: C (E = negative; slope of 3 =negative)**

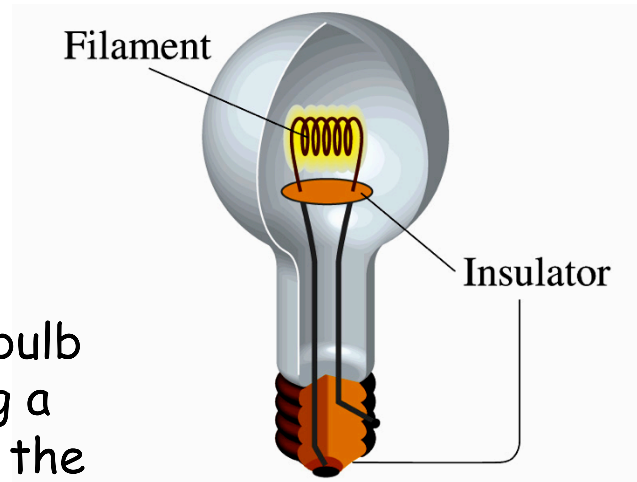
18. (4 pts.) For which part of its path is the electrostatic force largest in magnitude?
   A. segment 1
   B. segment 2
   C. segment 3
   D. segment 4
   E. none of the above

**Ans: D (slope=steepest)**

# $P = V^2 / R$ Example: bright and dim bulbs

1. How much current is "drawn" by a 100 W light bulb connected to a 120 V outlet?

$$I = \frac{P}{\Delta V_R} = \frac{(100\ \text{W})}{(120\ \text{V})} = 0.833\ \text{A}$$




2. How much power is used by a 60 W light bulb rated at 120 V if it is operated at 100 V, using a dimmer control? (Assume its resistance stays the same.)

$$\Delta V = \frac{P}{I} = \frac{P}{\Delta V / R} \quad \text{so} \quad R = \frac{(\Delta V)^2}{P} = \frac{(120\ \text{V})^2}{(60\ \text{W})} = 240\ \Omega$$

(from specifications: 120V bulb)

$$P = (\Delta V)^2 / R = (100\ \text{V})^2 / (240\ \Omega) = 42\ \text{W}$$

(100V, as used here)

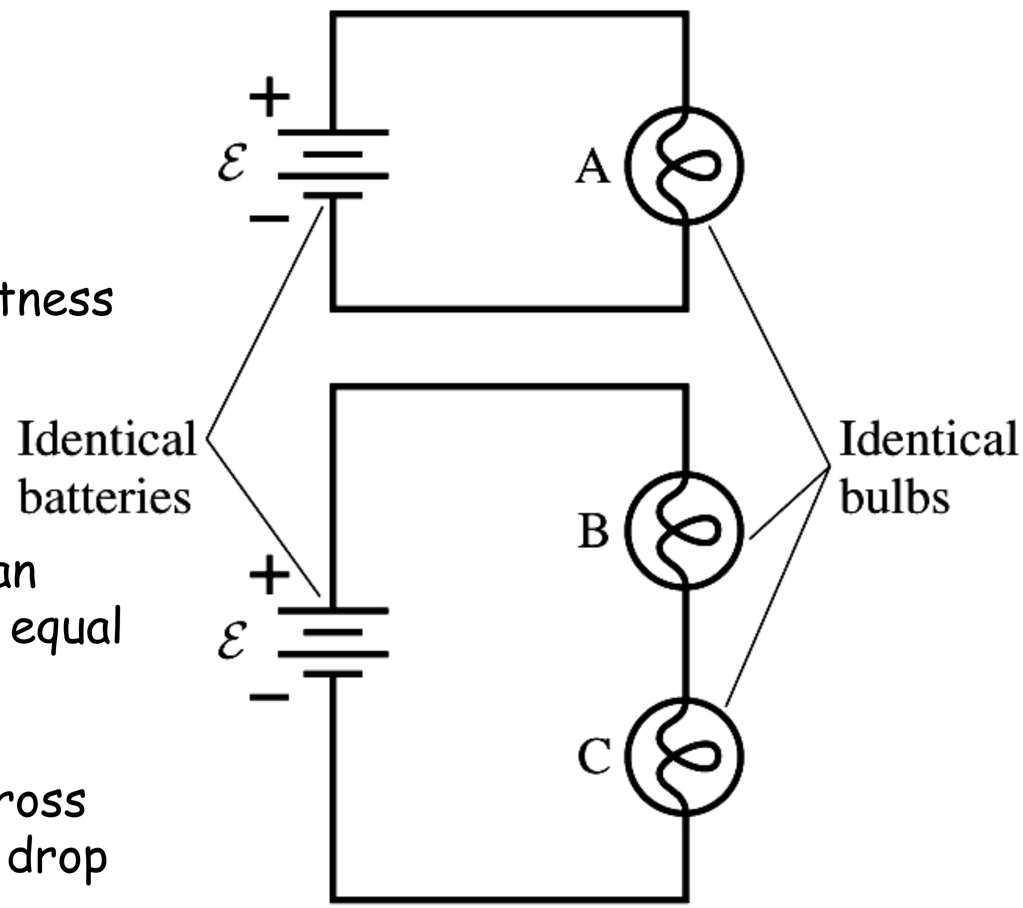
(Actually, the resistance at this lower operating V will be less than the R calculated here, because the filament temperature will be lower.

# Bulbs in Series

***Question:*** How does the brightness of bulb A compare with that of bulbs B and C?

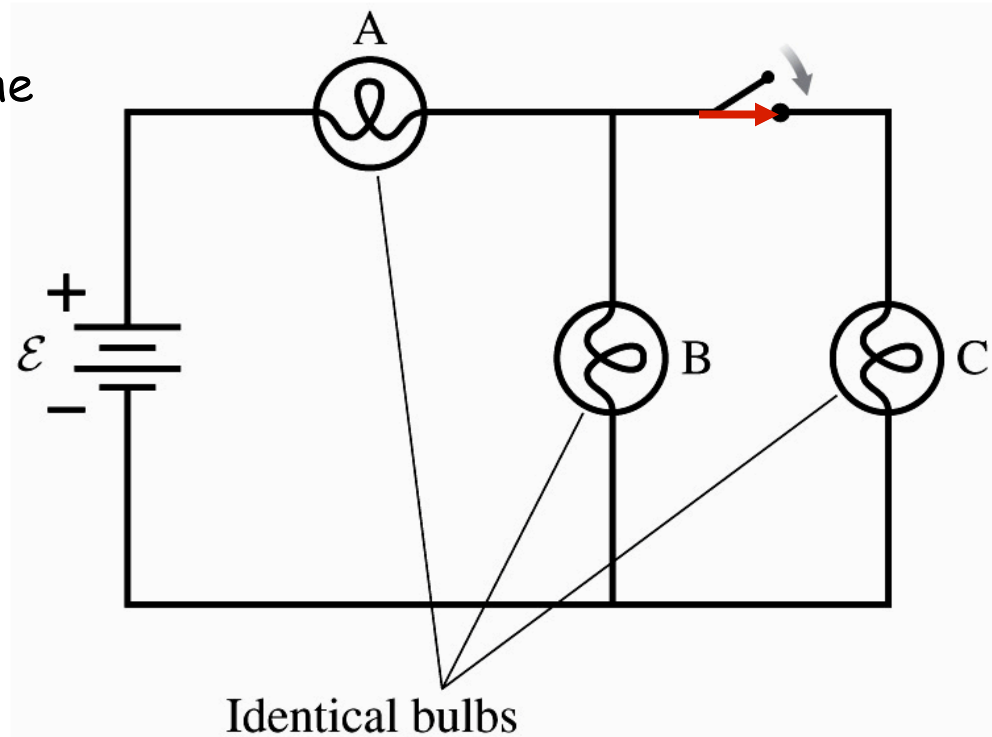
***Answer:*** Bulb A is brighter than bulb B and bulb C, which are of equal brightness.

***Reason:*** The potential drop across bulb A is **E**, while the potential drop across B and across C is **E**/2.



# Bulbs in Parallel

Initially, bulbs A and B have the same brightness and C is out. What happens to the brightness of the bulbs when the switch is closed?

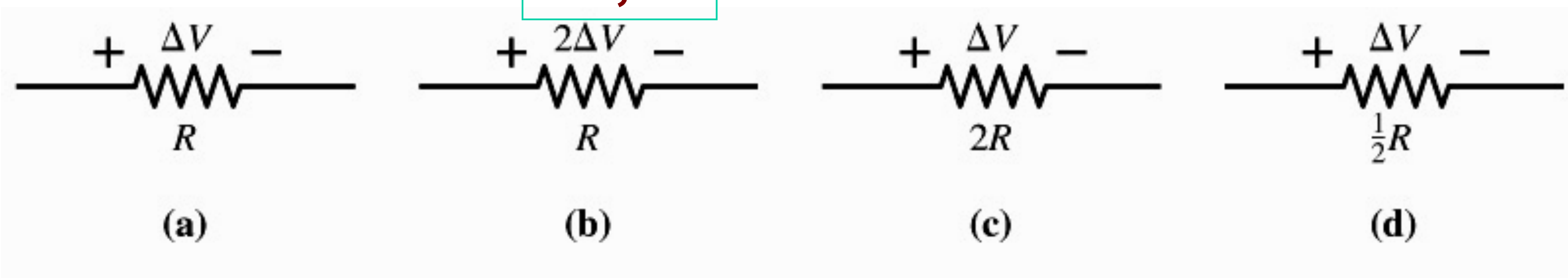



1. Bulb A gets brighter (because the overall current increases);
2. Bulb B gets dimmer (because current is diverted to Bulb C);
3. Bulb C glows with the same brightness as B (because they split the current equally).

# Clicker Question 15

Which resistor dissipates the most power?

V, R  **2V, R**  V, 2R  V, R/2



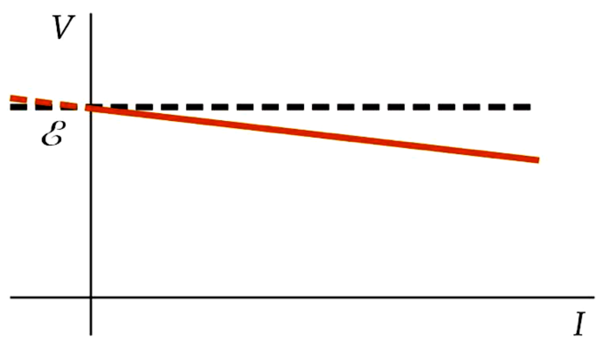

$$P \propto V^2 / R$$

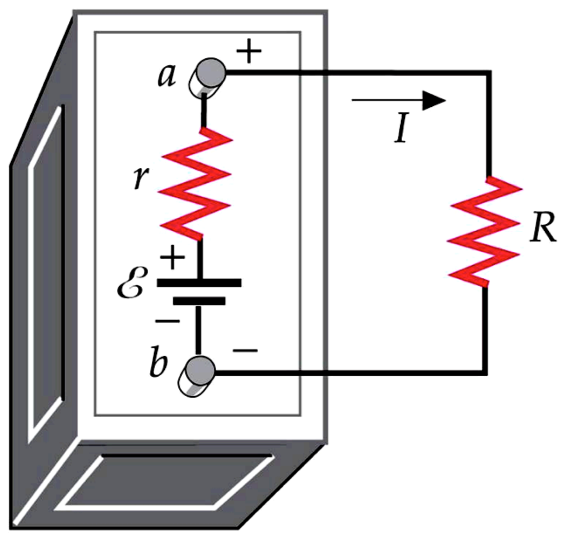
So power compared to case A is: B=4A, C=A/2, D=2A

Series circuits applications

## Real vs Ideal Batteries: Internal Resistance

Ideal batteries maintain $\mathcal{E}$ regardless of load, but
Real batteries have internal resistance
We model a real battery as ( ideal battery + resistor r )
so $\mathcal{E}$ on terminals comes after a voltage drop V= I r :




$$V_a = V_b + \mathcal{E} - I\,r$$

$$V_a - V_b = \mathcal{E} - I\,r$$

$$I\,R = V_a - V_b = \mathcal{E} - I\,r$$

$$I = \frac{\mathcal{E}}{R + r}$$

Current*time = charge
1 ampere-sec = 1 C
Large batteries are rated in A-hrs

$$1\text{ A h} = 3600\text{ C} \qquad E_{\text{stored}} = Q\mathcal{E}$$

Typical car batteries are rated 50 A-hr or more

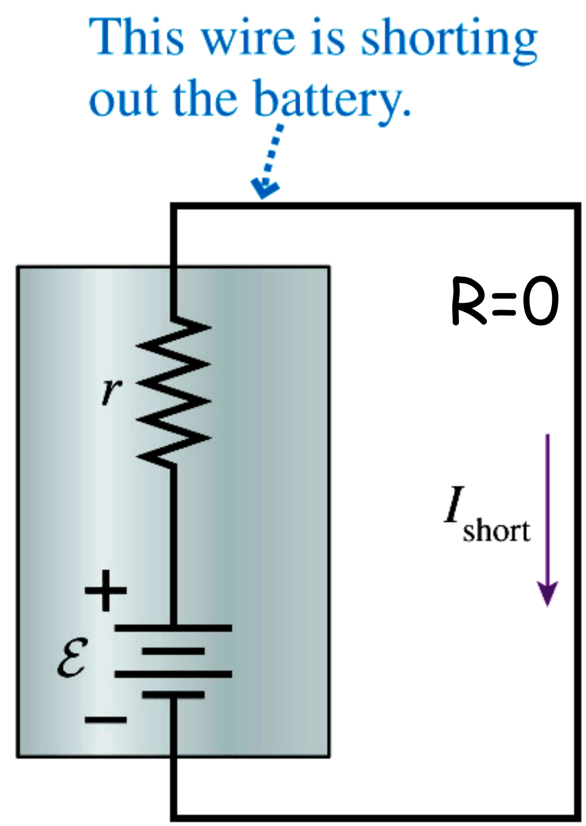
# Bad way to measure r: Short Circuits

"Short circuit" = zero R path for I.

What if you "short out" a battery, i.e., connect an ideal (R=0) wire across its terminals?
The potential difference across its terminals becomes zero, so
$I_{short}=\mathcal{E}/r$

All of the battery's EMF is now dropped across its internal resistance, *r*.

$I_{short}$ is the maximum possible current that the battery can supply
It is a measure of the internal resistance $r$ of the battery:
$r = \mathcal{E} / I_{short}$



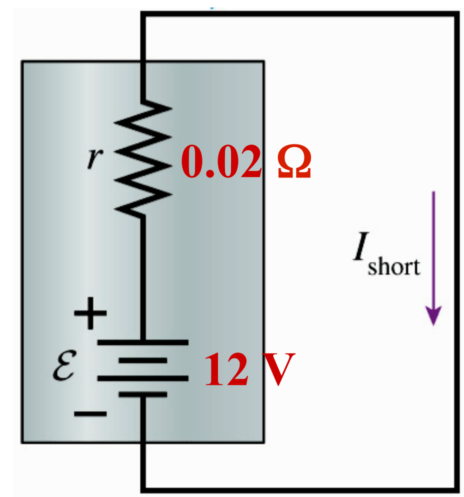
# Example:
# A Short-Circuited Car Battery

What is the short-circuit current of a 12 V car battery with an internal resistance of 0.020 Ω?

What happens to the power supplied by the battery when it is shorted?

$$I_{\text{short}} = \frac{\mathcal{E}}{r} = \frac{(12\ \text{V})}{(0.020\ \Omega)} = 600\ \text{A}$$

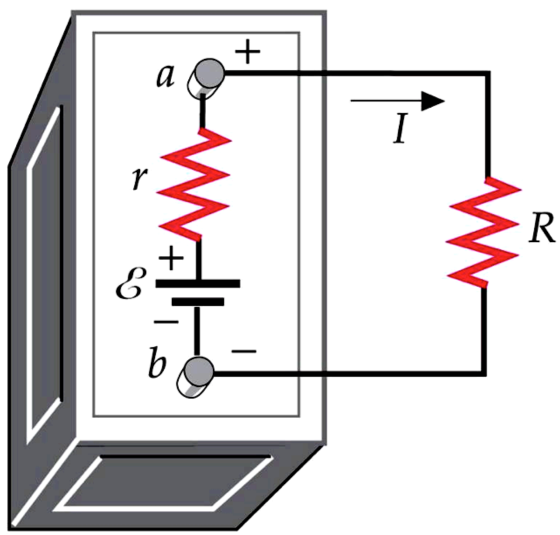
$$P = I^2 r = (600\ \text{A})^2 (0.020\ \Omega) = 7{,}200\ \text{W}$$




*All* of this power would be dissipated inside the battery, making it likely to explode.
Do not short out your car's battery!

# Better way to measure internal resistance

- We can determine the effective r in a battery by comparing "open-circuit voltage" (when I = 0) to the voltage we measure when some known current is drawn
  - Measure voltage across terminals a-b, with nothing connected: $V_0$
  - Attach some load and measure the current flowing, then also measure the voltage across the battery terminals, $V_I$
  - Then $V_0 = \mathcal{E}$, and $V_I = \mathcal{E} - I r$
  - So $r = (\mathcal{E} - V_I) / I$
- Example: 12 V car battery
  - Open-circuit, we measure $V_0$ = 12.0 V
  - With 2 amps current flowing, $V_I$ = 8.0 V
  - Then r = (12 – 8) /2 = 2 ohms
  - What will battery terminal voltage be for I=5A?




$V_{I=20A} = \mathcal{E} - I r$ = 12V – 5A(2 ohms)= 2 V

This battery is not very useful !

# Example: Lighting Up a Flashlight

A 6 Ω flashlight bulb is powered by a 3 V battery with internal resistance of 1 Ω. (Assume ideal wires.)

What is the power dissipation of the bulb in this circuit?

What is the terminal voltage of the battery when bulb is on?

$$I = \frac{\mathcal{E}}{R+r} = \frac{(3\text{ V})}{(6\ \Omega)+(1\ \Omega)} = 0.43\text{ A}$$

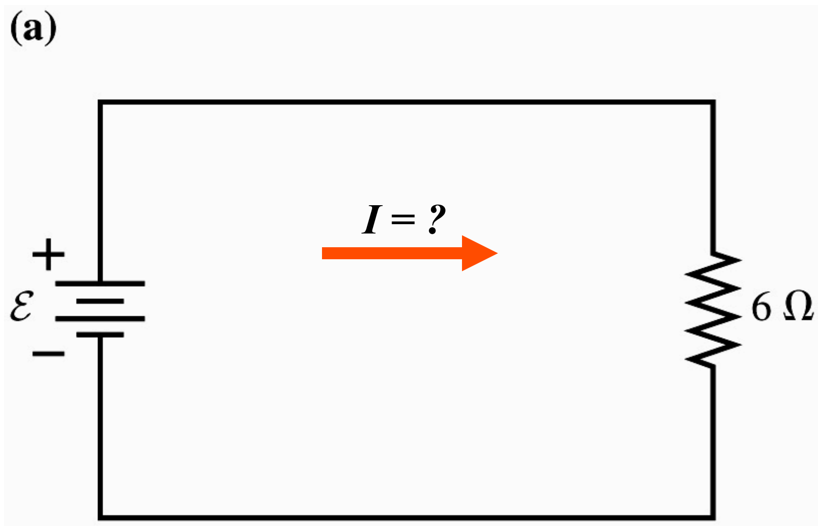
$$P_R = I^2 R = (0.43\text{ A})^2(6\ \Omega) = 1.1\text{ W}$$

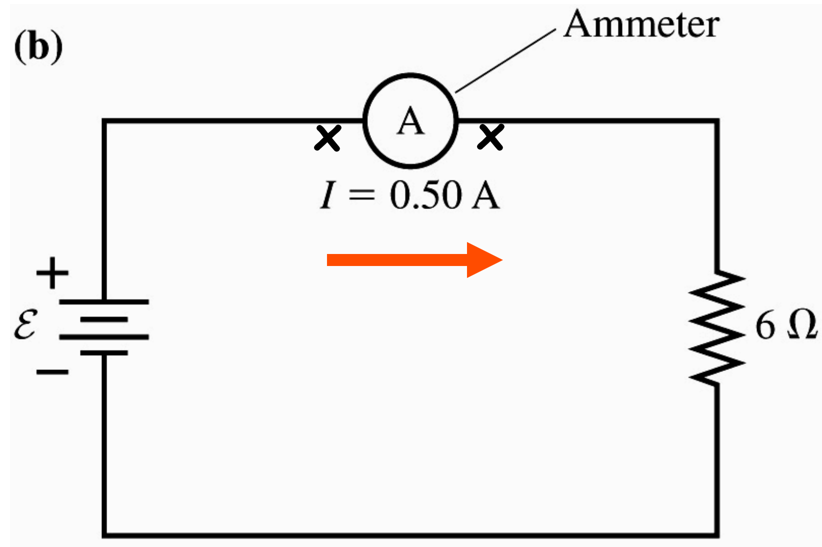
$$P_r = I^2 r = (0.43\text{ A})^2(1\ \Omega) = 0.185\text{ W}$$

About 15% of the total **power** consumed goes into heating the battery rather than lighting the bulb.

$$\Delta V_{\text{bat}} = \mathcal{E} - Ir = (3\text{ V}) - (0.43\text{ A})(1\ \Omega) = 2.57\text{ V}$$

# Ammeters




***Question:*** How can you measure the current in a circuit?

***Answer:*** You must ***break the circuit*** and ***insert*** an ammeter into the current.

***Ideal Ammeter:*** To have a minimum effect on the current being measured, the ammeter must have ***zero resistance***, so that there is zero potential difference across the ammeter. Electronic ammeters can give good approximations to this condition.

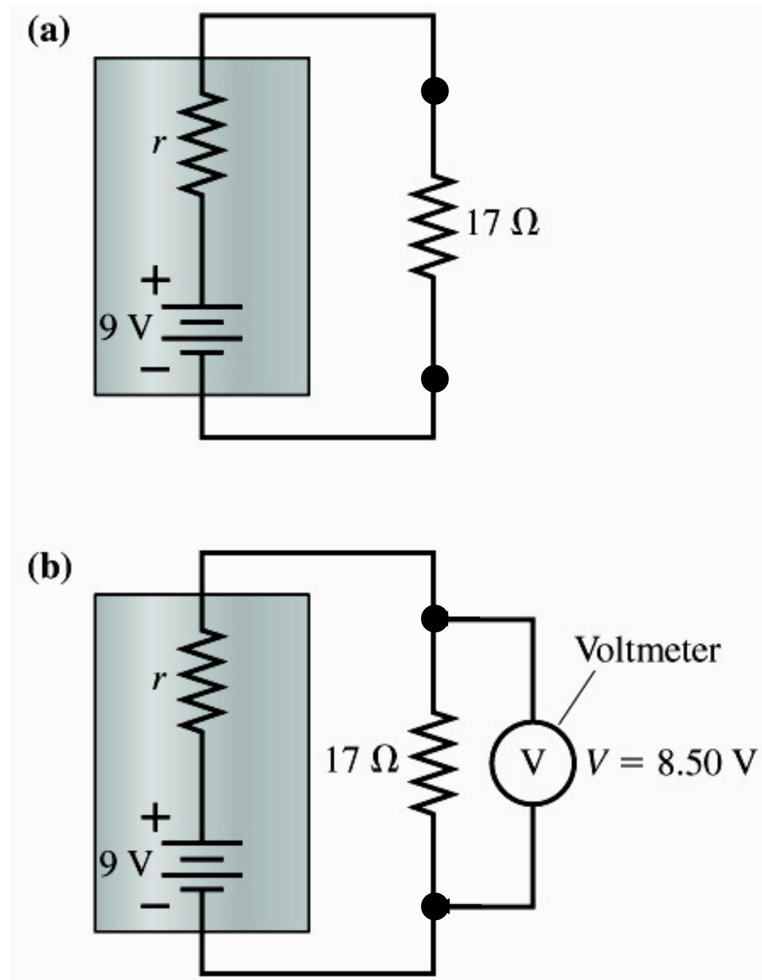
***Note:*** "Clip on" ammeters that measure AC current without breaking the circuit are commercially available. They use magnetic induction (...later).

# Voltmeters

***Question:*** How do you measure the potential difference between two points in a circuit?

***Answer:*** connect one lead of a voltmeter to each point.

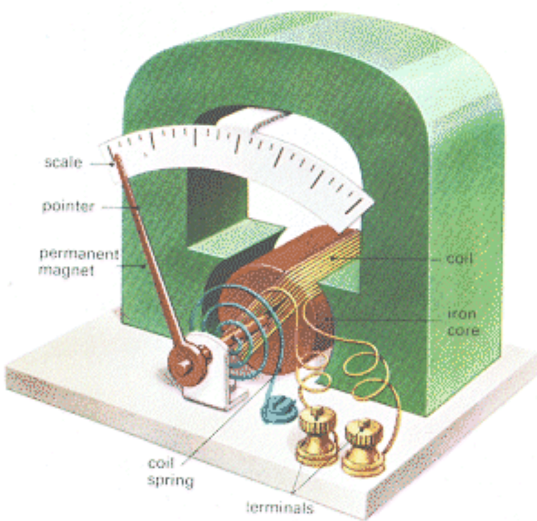
***Ideal Voltmeter:*** To have a minimum effect of the circuit being measured, the connected voltmeter must have ***infinite resistance***, so that no current is diverted through the voltmeter. Electronic voltmeters can give good approximations to this condition, but electro-mechanical voltmeters may not.



# So - What is a voltmeter or ammeter?

1. Old fashioned electro-mechanical meters (obsolete but still used)

- "Galvanometer" :
  - Coil in a magnetic field rotates in proportion to I in coil
  - We'll learn about how this works in a few days
  - Generic sensing device for 19th and early 20th C.
- Calibrate its deflection vs I : you have an **ammeter**
- To measure volts: use ammeter to measure I through a known large R
  - Large R, so I drawn by meter is very small – must not significantly affect circuit being measured !
  - Then V across meter terminals = I R, neglecting R of meter itself
- Then mark the meter face with V's corresponding to I values: **voltmeter**





# What is a voltmeter or ammeter?

- Modern digital meters
  - "Analog to digital converter" (ADC) chips produce computer-readable digits proportional to voltage across their inputs
  - If you want to measure I, put a small R across the ADC and measure V
    - Small R because you must not significantly affect current being measured
  - "Digital multimeter" = device that can measure I, V, or R, in one package