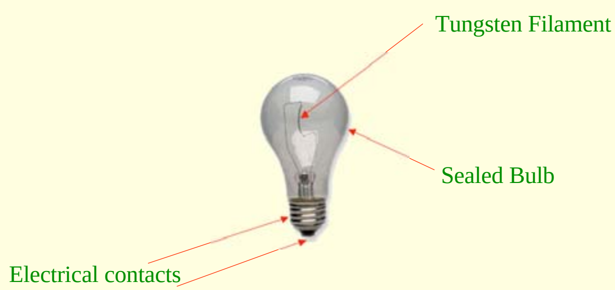
On the Brightness of Bulbs

Resistance
Blackbody Radiation
Ohm's Law

Review: What makes a bulb light up?

- The critical ingredient is closing a circuit so that current is forced through the bulb filament
  - more on filaments and what is physically going on later
- The more the current, the brighter the bulb
- The higher the voltage, the brighter the bulb
- Power "expended" is $P = VI$
  - this is energy *transfer* from chemical potential energy in the bulb to radiant energy at the bulb

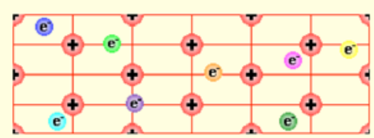
Bulb Design Basics



120 W bulb at 120 V must be conducting 1 Amp ($P = VI$)
Bulb resistance is then about 120 Ohms ($V = IR$)

What makes the bulb light up?

- Bulb contains a very thin wire (filament), through which current flows
- The filament presents resistance to the current
  - electrons bang into things and produce heat
  - a lot like friction
- Filament gets hot, and consequently emits light
  - gets "red hot"



Everything is Aglow

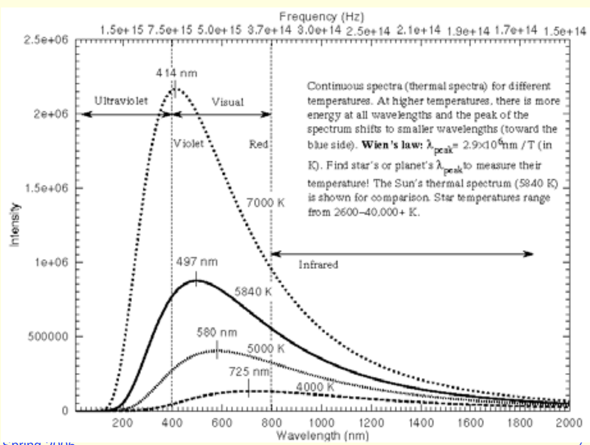
- All objects emit "light"
  - Though almost all the light *we* see is *reflected* light
- The color and intensity of the emitted radiation depend on the object's temperature
- Not surprisingly, our eyes are optimized for detection of light emitted by the sun, as early humans saw most things via reflected sunlight
  - no light bulbs, TVs
- We now make some artificial light sources, and ideally they would have same character as sunlight
  - better match to our visual hardware (eyes)

Color Temperature

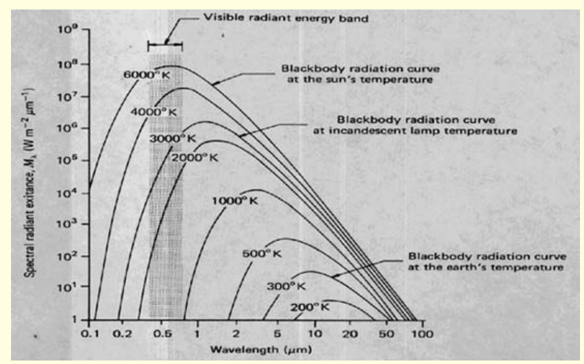
Object	Temperature	Color
You	~ 30 C ≈ 300 K	Infrared (invisible)
Heat Lamp	~ 500 C ≈ 770 K	Dull red
Candle Flame	~ 1700 C ≈ 2000 K	Dim orange
Bulb Filament	~ 2500 C ≈ 2800 K	Yellow
Sun's Surface	~ 5500 C ≈ 5800 K	Brilliant white

The hotter it gets, the "bluer" the emitted light
The hotter it gets, the **more intense** the radiation

The "Blackbody" Spectrum



Blackbody spectra on logarithmic scale



Sun peaks in visible band (0.5 microns), light bulbs at 1 µm, we at 10 µm.
(note: 0°C = 273°K; 300°K = 27°C = 81°F)

Bulbs aren't black! Blackbody??!!

- Black in this context just means reflected light isn't important
- Hot charcoal in a BBQ grill may glow bright orange when hot, even though they're black
- Sure, not everything is truly black, but at thermal infrared wavelengths (2–50 microns), you'd be surprised
  - your skin is 90% black (absorbing)
  - even white paint is practically black
  - metals are still shiny, though
- This property is called emissivity:
  - radiated power law modified to $P = \varepsilon A \sigma T^4$, where ε is a dimensionless number between 0 (perfectly shiny) and 1.0 (perfectly black)
  - σ, recall, is 5.67×10^{-8} in MKS units, T in Kelvin
- Why do we use aluminum foil?

What Limits a Bulb's Lifetime

- Heated tungsten filament drives off tungsten atoms
  - heat is, after all, vibration of atoms: violent vibration can eject atoms occasionally
- Tradeoff between filament temperature and lifetime
  - Brighter/whiter means hotter, but this means more vigorous vibration and more ejected atoms
  - "Halogen" bulbs scavenge this and redeposit it on the filament so can burn hotter
- Eventually the filament burns out, and current no longer flows – no more light!
- How "efficient" do you think incandescent bulbs are?
  - Ratio between energy doing what you want vs. energy supplied
  - Efficiency = (energy emitted as visible light)/(total supplied)

Predicting Brightness in Bulb Networks

- This is a very instructive (and visual) way to learn about the behavior of electronics, how current flows, etc.
- The main concept is Ohm's Law:

$V = IR$ voltage = current × resistance

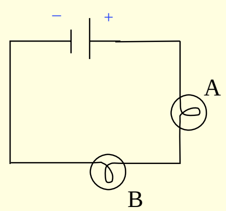
- We've already seen voltage and current before, but what's this R?
- R stands for resistance: an element that impedes the flow of current
  - measured in Ohms (Ω)
- Remember the bumper-cars nature of a bulb filament? Electrons bounce off of lattice atoms
  - this constitutes a resistance to the flow of current

Interpretation of Ohm's Law

- The best way to think about Ohm's law is:
  - when I have a current, I, running through a resistance, R, there will be a voltage drop across this: $\Delta V = IR$
  - "voltage drop" means change in voltage
- Alternative interpretations:
  - when I put a voltage, V, across a resistor, R, a current will flow through the resistor of magnitude: $I = V/R$
  - if I see a current, I, flow across a resistor when I put a voltage, V, across it, the value of the resistance is $R = V/I$
- Ohm's Law is key to understanding how current decides to split up at junctions
  - try to develop a qualitative understanding as well as quantitative

Bulbs in Series

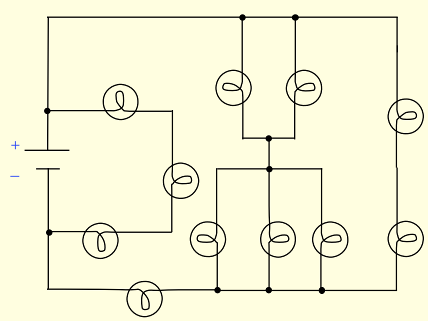
- Each (identical) light bulb presents a “resistance” to the circulating electrical current
- Adding more bulbs *in series* adds resistance to the current, so less current flows



Which bulb is brighter? WHY?

Answer

- There is only one current flowing, and it goes through both bulbs. They will therefore shine with equal brightness.
  - Imagine exchanging bulbs. Does this change anything?



Bulbstravaganza

Exploration of Circuits & Ohm’s Law

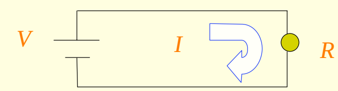
Reminder: Ohm’s Law

- There is a simple relationship between voltage, current and resistance:

$$V = I R$$

Ohm’s Law

V is in Volts (V)
I is in Amperes, or amps (A)
R is in Ohms (Ω)



Numerical examples of Ohm's Law ($V = I \cdot R$)

- How much voltage is being supplied to a circuit that contains a 1 Ohm resistance, if the current that flows is 1.5 Amperes?
- If a 12 Volt car battery is powering headlights that draw 2.0 Amps of current, what is the effective resistance in the circuit?

Answer #1:

(How much voltage is being supplied to a circuit that contains a 1 Ohm resistance, if the current that flows is 1.5 Amperes?)

- Use the relationship between Voltage, Current and Resistance, $V = IR$.
- Total resistance is 1 Ohm
- Current is 1.5 Amps

So $V = IR$ = (1.5 Amps)(1 Ohms) = 1.5 Volts

Answer #2

(If a 12 Volt car battery is powering headlights that draw 2.0 Amps of current, what is the effective resistance in the circuit?)

- Again need $V = IR$
- Know I, V, need R
- Rearrange equation: $R = V/I$
  = (12 Volts)/(2.0 Amps)
  = 6 Ohms

Conductors are at Constant Voltage

- Conductors in circuits are idealized as zero-resistance pieces
  - so $\Delta V = IR$ means $\Delta V = 0$ (if $R = 0$)
- Can assign a voltage for each segment of conductor in a circuit

batteries in parallel add *energy*, but not voltage

batteries in series add voltage

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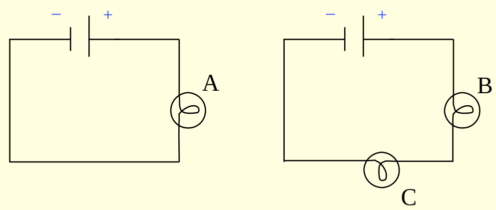
Multi-bulb circuits

Rank the expected brightness of the bulbs in the circuits shown, e.g. A>B, C=D, etc. WHY?!



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Answer:

- Bulbs B and C have the same brightness, since the same current is flowing through them both.
- Bulb A is brighter than B and C are, since there is less total resistance in the single-bulb loop, so

A > B=C.

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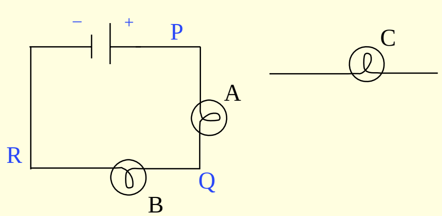
Adding Bulbs

- Where should we add bulb C in order to get A to shine more brightly?



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Answer

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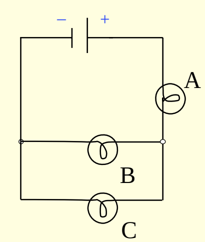
- The only way to get bulb A to shine more brightly is to increase the current flowing through A.
- The only way to increase the current flowing through A is to decrease the total resistance in the circuit loop
- Since bulbs in parallel produce more paths for the current to take, the best (and only) choice is to put C in parallel with B:



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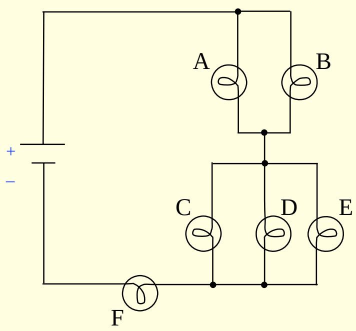
A more complex example!



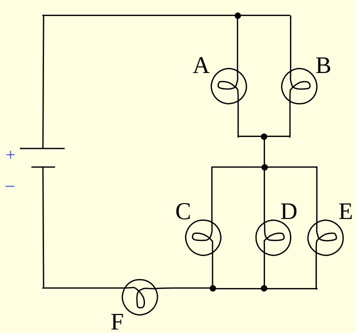
Predict the relative brightness of the bulbs

Answer

- The entire current goes through bulb F so it's going to be the brightest
- The current splits into 3 branches at C,D,E and they each get 1/3 of the current
- The current splits into 2 branches at A,B and they each get half the current, so

F > A = B > C = D = E

If I disconnect bulb B, does F get brighter or fainter?



Answer

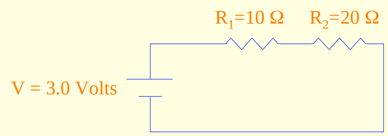
- By disconnecting B, the resistance of the (AB) combination goes up, so the overall current will be reduced.
- If the current is reduced, then F will be less bright.

Power Dissipation

- How much power does a bulb (or resistor) give off?
  - $P = VI$
  - but $V = IR$
  - so $P = I^2R$ and $P = V^2/R$ are both also valid
- Bottom line: for a fixed resistance, power dissipated is dramatic function of either current *OR* voltage

How about multiple resistances?

- Resistances in series simply add
- Voltage across each one is $\Delta V = IR$

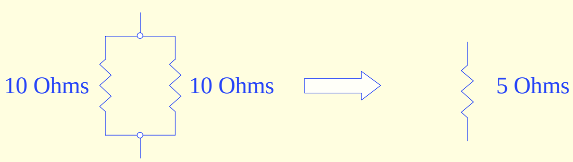


Total resistance is 10 Ω + 20 Ω = 30 Ω
So current that flows must be $I = V/R$ = 3.0 V / 30 Ω = 0.1 A
What are the Voltages across R_1 and R_2?

Parallel resistances are a little trickier….

- Rule for resistances in parallel:

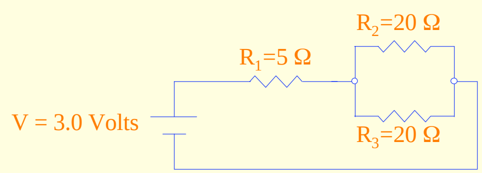
$$1/R_{tot} = 1/R_1 + 1/R_2$$



Can arrive at this by applying Ohm's Law to find equal current in each leg. To get twice the current of a single10 Ω, could use 5 Ω.

A Tougher Example

- What is the voltage drop across the 3 resistors in this circuit?



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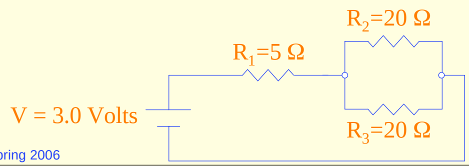
Answer

- First, need to figure out the current that flows in the circuit. This depends on the total resistance in the loop.
- Combine the parallel resistors into an equivalent single series resistor, the parallel pair are equal to a single resistor of 10 Ohms
- The total resistance in the loop is 5 + 10 = 15 Ohms
- So the total current is $I = V/R$ = 3/15 = 0.20 Amps
- Voltage across R_1 is $V = IR$ = 0.2A × 5 Ohms = 1 Volt
- Voltage across R_2, R_3 is equal, $V = IR$ = 0.2A × 10 Ω = 2 V
- Note that the sum of the voltage drops equals battery voltage!



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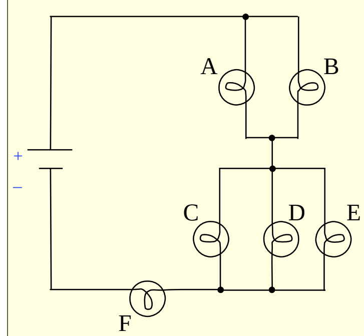
Complex Example



- Say battery is 5.5 Volts, and each bulb is 6Ω
- AB combo is 3Ω
- CDE combo is 2Ω
- total resistance is 11Ω
- current through battery is 5.5V/11 Ω = 0.5 A
- A gets 0.25 A, so ΔV = 1.5V
- C gets 0.1667 A, so ΔV = 1.0 V
- F gets 0.5 A, so ΔV = 3.0 V
- note voltage drops add to 5.5 V
- Use V^2/R or I^2R to find:
  - P_{AB} = 0.375 W each
  - P_{CDE} = 0.167 W each
  - P_F = 1.5 W

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Assignments

- Read pp. 224–231, 332–333, 407 for *this* lecture
- HW #3: Chapter 10: E.2, E.10, E.32, P.2, P.13, P.14, P.15, P.18, P.19, P.23, P.24, P.25, P.27, P.28, P.30, P.32
- Next Q/O (#2) due *next* Friday: only submit one this week if you missed it last week.

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