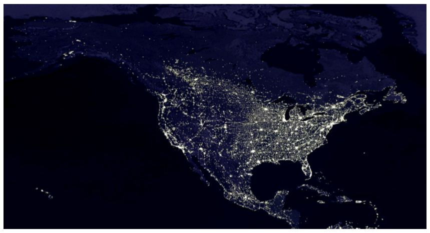
Light bulbs



Lecture 17 :
Incandescent light bulbs
How they work
Why they are inefficient

Reminders:
No HW was due yesterday
HW for next week, posted soon
Reading quiz Thurs

Lightbulbs

How many scientists does it take to change a lightbulb?
Undergraduates:
None "Bright light - hurts... must go back to bed".
Postgraduates:
Funding for a new lightbulb ran out six months ago - will have to borrow from their parents.
***Apple* engineers:**
Seven. One to change the bulb, six to design t-shirts and new gadgets
Russian military scientists:
It's top secret.
Nuclear engineers:
One to install the bulb and six to figure out what to do with the old bulb for the next ten thousand years

Lecture 17 :
Incandescent lightbulbs
How they work
Why they are inefficient

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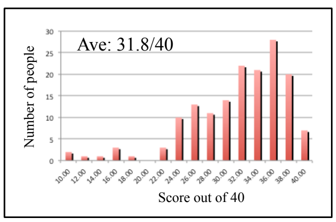
Midterm 2 results



•Great job
•Make sure that you understand questions that you got wrong.
• This material will come up again!
• Solutions on D2L,
•See web for resources:
  •office hours,
  •helproom (not just by us 9-5),
  •email after class etc.

End of semester grade policy

At end of semester I will:
• Drop your lowest midterm score, lowest HW, 2 classes.
• Add up all points possible during class to get final score and %
• Based on that %, you are guaranteed the following grade:
  > 90 % = A
  > 80 % = B
  > 70 % = C
  > 60 % = D
  < 50 % = F
I reserve the right to make this scale (curve) more generous/ inclusive.

Hope to have your mid-term scores posted this week or next.

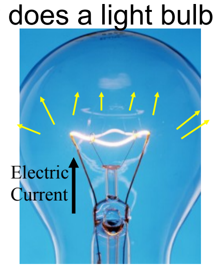
Light bulbs

Use vast quantities of energy- ~18% of electrical energy for lighting.
Incandescent (regular) light bulbs waste 88% of that!!

- How do they work?
- What determines color?
- Why do they "burn out"?
- Why are fluorescent lights are more efficient?
- Why is it hard to improve efficiency?

Physics:
• Introduction to electromagnetic radiation (light and other stuff)
• EM radiation emitted by all objects
  - Spectrum – range of colors
  - Power – Stefan Boltzman Law

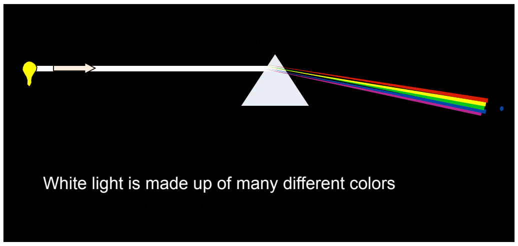
How does a light bulb work?



How does an incandescent light bulb work:
• Electric current flows through filament
• Filament gets hot
• Hot filament emits EM radiation
• Electrical energy → EM radiation energy

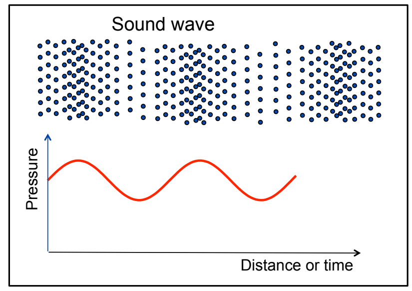
What can we see coming out of a light bulb?

We can see white(ish) light:
- Visible light is one type of electromagnetic radiation
- Form of energy
- Consists of many different colors – what's a color?

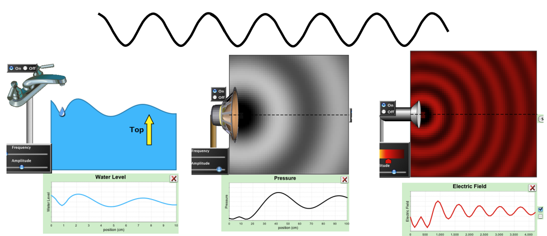


Electromagnetic radiation

EM radiation travels in waves, like sound, waves on a string etc



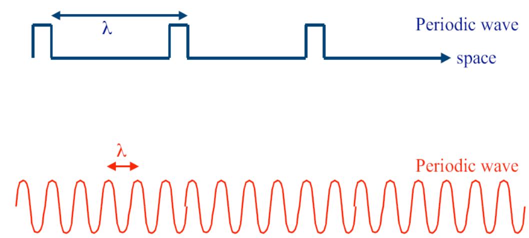
The goal of this class: Making sense of waves



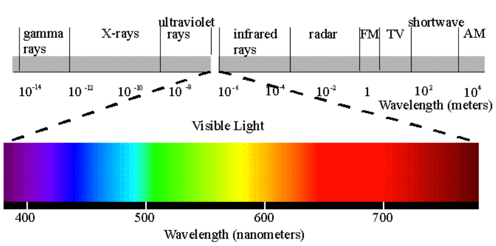
-For Water Waves?
-For Sound Wave?
-For E/M Waves?

Wavelength

For *periodic* waves, we can identify a *wave length*, λ, by measuring the *distance* between unique points



Electromagnetic waves can have any wavelength
Scientific notation is useful!



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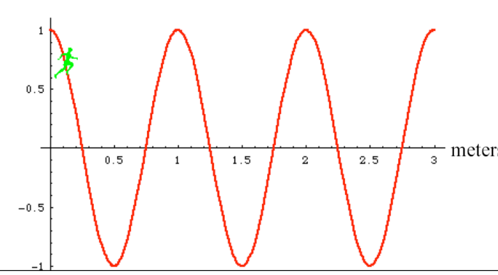
Wavelength of a Wave

What is the wavelength of the red wave?

A) 1m
B) 2m
C) 3m



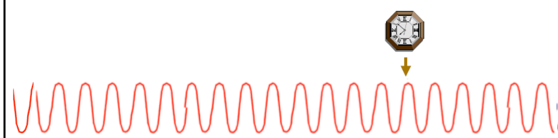
How Big is that wave of light?

- The wavelength of green light is around 500 nm. How many wavelengths of green light fit into one cm (0.4 inches, or a fingertip)?
  a) 20 thousand
  b) 50 thousand
  c) Two million
  d) Two billion
  e) 5 billion

- How many A's in a B
  (e.g. quarters in a dollar!)
  Number = B / A
- wavelength = A
  500 nm =
  $5 \times 10^{2} \times 10^{-9}$ m =
  5×10^{-7} m
- 1 cm is 1/100 of a meter and 10^{-2} m B
- Therefore, we obtain
  10^{-2} m / 5×10^{-7} m $= 2 \times 10^{4}$
- There are 20,000 wavelengths in a cm N = B/A

Period and Frequency

For *periodic* waves, we can identify a *period*, T, by measuring the time taken for a wavelength λ to pass a given point -



Speed, wavelength, frequency

Speed = "c" in a vacuum

Wavelength (lambda), or how wide each oscillation is (meters)

$$v = f\lambda$$

$$v = \nu\lambda$$

Either wavelength or frequency will tell you the color of light

Units:
m/s = waves/sec * meters/wave

Frequency, or oscillations per second (Hertz). *v* or *f*

So => $c = \upsilon\lambda$ or $\upsilon = c/\lambda$ or $\lambda = c/\upsilon$
$c = f\lambda$ or $f = c/\lambda$ or $\lambda = c/f$

So knowing the **frequency**, we can calculate the **wavelength**

Or knowing the **wavelength**, we can calculate the **frequency**

For light waves, the speed in air or vacuum is 3×10^{8} meters/sec

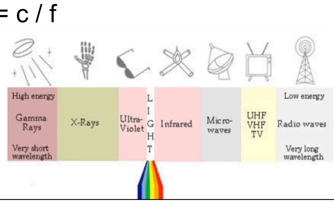
Review of λ, T, f, c

Waves (light): Wavelength λ, period T, frequency f, and speed c.

$c = \lambda/T = \lambda f$

or $f = c / \lambda$

or $\lambda = c / f$



Practice with E/M Waves

An FM radio station transmits at a frequency of: f = 100 MHz = 10^{8} Hz (note: Hz = 1/s) then the wavelength is :

A) 1 m B) 0.3 m C) 3 m D) 100 m

E) None of these.

$c = \lambda f$

$f = c / \lambda$

$\lambda = c / f$

$\lambda = (3 \times 10^{8}\ \text{m/s}) / (10^{8}\ 1/\text{s}) = 3$ m

Clicker Question

Your microwave oven operates at a frequency of:
f = 3 GHz = $3x10^9$ Hz (note: Hz = 1/s)
then the wavelength is :

A) 1 cm B) 0.3 cm C) 3 cm D) 30 cm
E) None of these.

$c = \lambda f$

$f = c / \lambda$

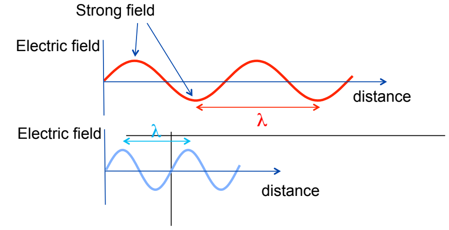
$\lambda = c / f$

$\lambda = [3 \times 10^8 \text{ m/s}] / [3x10^9 \text{ 1/s}]$

$\lambda = 0.1$ m Or 10cm

Electromagnetic radiation

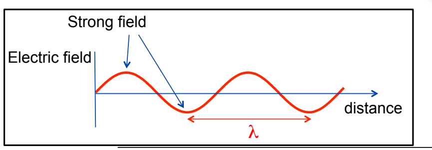
- EM radiation also travels in waves, like sound
- But light can travel through a vacuum so what exactly is 'waving'?
- EM radiation is a periodic modulation of "electric field"



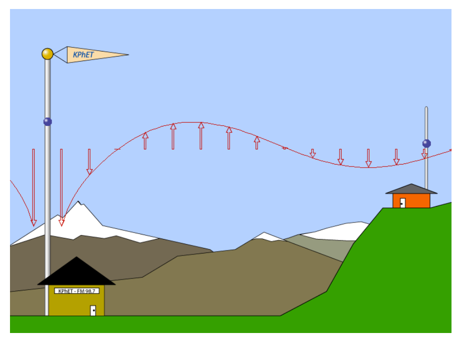
- Color of light depends on its wavelength.

What is Electric field?

- Light is periodic modulation of "electric field"



- Electric field exists everywhere in space
- Describes the force on a charged particle at each point in space
- Vector – has a magnitude and direction
- Units: Newtons/Coulomb
- Contains energy
- Created by charges (and created in other ways)
- Analogy: Like gravitational field describes the force on a particle with mass
- Balloon demo

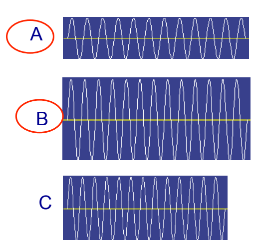


http://phet.colorado.edu/en/simulation/radio-waves

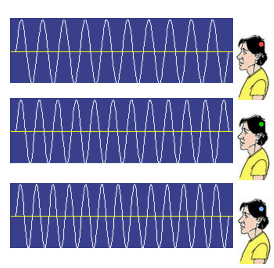
Clicker questions

- Which of the light waves has the longest wavelength?
- Which of the light waves is brightest?
- Which of the light waves has the highest speed in empty space?

a) b) c)
e) They all have the same speed



We see color when waves of *different* wavelengths enter enter our eyes!



Light with wavelength of **650 nm** appears **red** when it enters a viewer's eye

Light with wavelength of **520 nm** appears **green**

Light with wavelength of **470 nm** appears **blue** when it enters a viewers eye

The speed of light in empty space is the *same* for all wavelengths

Speed of light & Distances

Can use Speed of light to measure distances (if we track time)

What Equation do we use?

$$d = r * t$$

If it takes 5 seconds for light to travel from here to a spaceship, How far is the spaceship ?

Work it out!

Dist = rate x time $= (3 \times 10^8 \text{ m/s})(5 \text{ s})$
$= 15 \times 10^8$ m
$= 1.5 \times 10^9$ m
$= 1.5 \times 10^6$ km

9.3×10^5 miles, or 930,000 miles

Properties of light

1. Light travels in vacuum.
   Sound travels in air (no sound in vacuum).

2. Light carries **energy**. (Sunlight warms, generates electricity.)

3. Light moves with a particular **speed** in vacuum,

4. Light travels in vacuum in straight lines (**rays**).

5. Light has **amplitude** (intensity).

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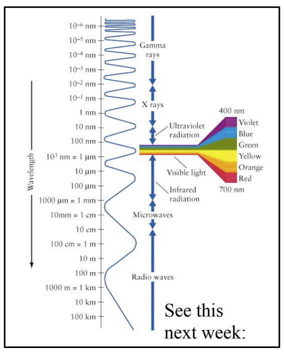
The electromagnetic spectrum



- All EM radiation is a periodic modulation of an electric field
- Visible light is just one part of the electromagnetic spectrum with specific range of λ (and f)
- Visible light is the strongest part of the EM spectrum emitted by the sun
- It is the part of the EM that our eyes can detect

Electromagnetic radiation

Light travels in waves, like sound

Speed of light, in vacuum
$c = 3 \times 10^8$ m/s

Frequency of red light
$= 4.6 \times 10^{14}$ Hz

Wavelength of red light =
a) 0.75 m
b) 7.5×10^{-5} m
c) 6.5×10^{-7} m
d) 1.38×10^{23} m

$c = \lambda f$
$f = c / \lambda$
$\lambda = c / f$

Electromagnetic radiation

Light travels in waves, like sound

$c = \lambda f$
$f = c / \lambda$
$\lambda = c / f$

Answer:
$\lambda = c/f$
$= (3 \times 10^8)/(4.6 \times 10^{14})$
$= 6.5 \times 10^{-7}$m
= 650 nm

($1\text{nm} = 1 \times 10^{-9}$m)

Speed of light, in vacuum
$c = 3 \times 10^8$ m/s

Frequency of red light
$= 4.6 \times 10^{14}$ Hz

Wavelength of red light =
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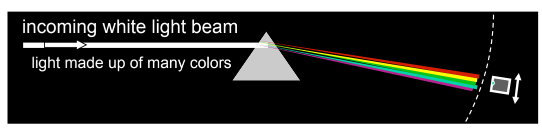
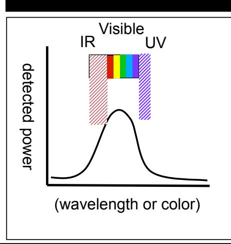
The spectrum of white light?

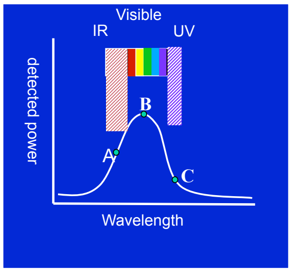
A spectrometer measures the spectrum (range of wavelengths or frequencies) in light





White light
- Defined as the spectrum of EM radiation emitted by the sun
- All visible λ present with roughly equal intensity

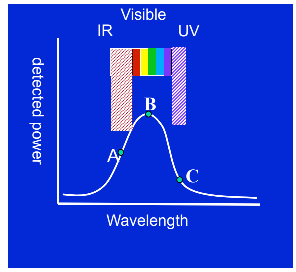
Understanding a spectrum:



For this spectrum, rank power of light at each color:

a. C greater than B greater than A
b. A greater than B greater than C
c. C greater than A greater than B
d. B greater than A greater than C
e. Cannot tell from this data.

Understanding a spectrum:



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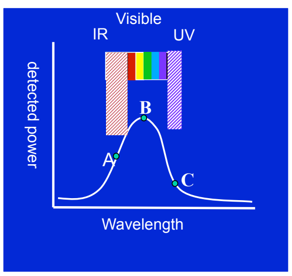
d. B greater than A greater than C
e. Cannot tell from this data.

An object is giving off light with this spectrum. What color in the emitted light has the most power?

a. IR,
b. Yellow/green
c. UV,
d. red,
e. blue,

Understanding a spectrum:



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d. red,
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Blackbody spectrum

- Everything that has a non-zero temperature emits EM radiation
- The spectrum of EM radiation coming from a black object is called the “blackbody spectrum.”
- Go to the blackbody spectrum simulation
- BB spectrum determined by temperature only.
- The temperature of the object affects both
  - The total power of EM radiation emitted by the object
  - The range of wavelengths emitted (the spectrum)

Blackbody spectrum and temperature

Look at light bulb with variac to control how much electrical power goes into it.

If I put half as much electrical power into it, what will happen?

a. color will change, get whiter, brightness decrease
b. color will stay the same, brightness decrease
c. color will get redder, brightness decrease
d. color will get redder, brightness the same
e. color will get whiter, brightness the same.