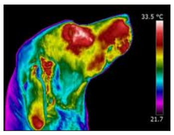
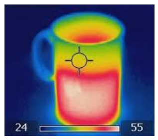
light bulbs, temperature, spectra, power

Why do night vision goggles see? And why?

Lecture 18 :
Blackbody spectrum
Improving light bulb efficiency

Reminders:
HW 7 due Monday 29th at midnight
Reading for Tuesday: Section 10.1

EM radiation so far

- EM radiation is a periodic modulation of the electric field: travels as a wave
- Wavelength (or frequency) determines:
  - type of EM radiation
  - if in visible range, wavelength determines color of light
- Spectrum of a source : plot of EM power (or intensity) emitted as a function of λ
- White light:
  - Light appears white when it contains all visible colors at roughly equal intensity
  - Technically defined as the spectrum of light emitted from sun

Today

- Look at EM radiation emitted by all objects – black body spectrum
  - Total power emitted
  - Range of wavelengths emitted
- Why are incandescent light bulbs inefficient?
- Why is it difficult to improve light bulb efficiency?
- IR radiation

Questions about Electric Field? what is oscillating? or Light?

Reading Quiz

1.The black body spectrum describes
   a. The wavelengths and intensities of EM radiation emitted by black objects
   b. The wavelengths and intensities of only visible light emitted by hot black objects
   c. The intensity of visible light emitted by black objects only
   d. The wavelengths and intensities of EM radiation emitted by objects that are glowing hot.
   e. Something that you might meet on Halloween

2. A thin nylon windbreaker helps keep you warm on a breezy day by

3.

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.

Blackbody spectrum and temperature

- Everything that has a non-zero temperature emits a spectrum of EM radiation
- The spectrum of EM radiation coming from a black object is called the "blackbody spectrum."
- Black object: Absorbs and emits all EM λ easily
- 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)

Temperature and total emitted power (brightness)

Stefan-Boltzman law gives total electromagnetic power (energy/second) out of a hot object at temperature T

Power = e X σ X T^4 X a

Area of surface

Temperature of object (in Kelvin!)

Stefan-Boltzmann constant,
$\sigma = 5.67 \times 10^{-8}$ J/(s m^2 K^4)

e = "emissivity"; how well the light gets out

Two burners on the stove are at the same temperature, but the left-hand burner has twice the area. How much more infrared radiation is it putting out?

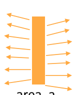
a) The same amount
b) Twice as much
c) Half as much
d) Four times as much
e) Sixteen times as much.

Power = e X σ X T^4 X a

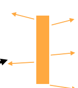
Comments on Stefan-Boltzman Law

Power = e X σ X T^4 X a

1. Emissivity (e)



- Property of surface,
- Scale of 0 to 1.
- 1 (BB) means radiates well, 0 is lousy.



area, a
e = 0.9

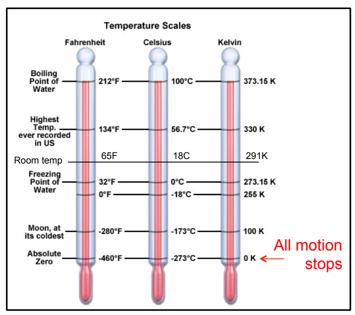
same T so same color.

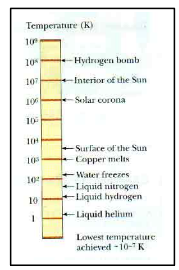
area, a
e = 0.3

2. T in Kelvin (= T Celsius +273)

3. Emitted power rises very quickly with temperature

The Kelvin Temperature Scale: Links T to motion





- 1 degree Kelvin = 1 degree Celsius = 9/5 degree Fahrenheit
- 0 degree Celsius = 273 K

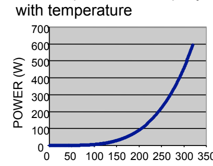
A particular light bulb's filament is at 2000 C. What is its temperature in Kelvin?

a) 2000 K
b) 2273 K
c) 1727 K
d) 2500 K

How does temperature affect emitted power (brightness)?

P = eσT^4a
$\sigma = 5.67 \times 10^{-8}$ J/(s m^2 K^4).
T in Kelvin (= T Celsius +273)

Emitted power rises rapidly with temperature



If I raise temperature of heating coil on stove from 450K to 500K, by what fraction will power emitted by coil increase?

⇒ Power at 500K / Power at 450K

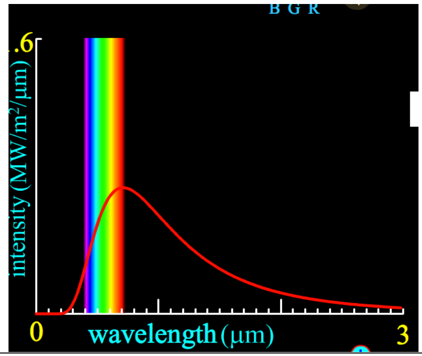
(note: emissivity and coil area will cancel!)

a. Power is 1.11 times larger.
b. Power is 250 times larger.
c. Power is 1.52 times larger.
d. Power is 5.0 times larger.
e. Power is 50 times larger

Blackbody spectrum

- Everything that has a non-zero temperature emits EM radiation
- The spectrum of EM radiation coming from a heated object is called the "blackbody spectrum." (Although it isn't black!)
- Go to the blackbody spectrum simulation
- The temperature of the object affects both
  - The total power of EM radiation emitted by the object ($P \propto T^4$) ✓
  - The range of wavelengths emitted (the spectrum)

Where does this Spectrum Come From?

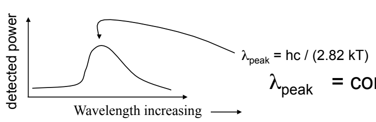


The funny shape of the black body spectrum

The shape of the spectrum for the thermal radiation of an object is rather complicated, but with some effort it can be understood and a formula derived that describes it. That is **beyond what we cover for this class,** but in case you are interested, the formula for the amount of power at each frequency ν of an electromagnetic wave is given by

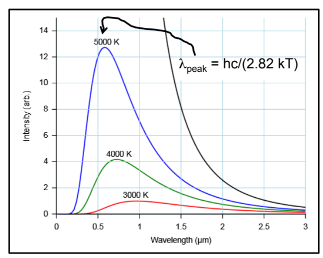
$P = (8\pi h/c3)\nu^3\ (e h\nu/kT - 1)^{-1}$,

where k is the Boltzmann constant (= 1.38×10^{-23} Joules/Kelvin),
c is the speed of light (3×10^8 m/s), h is Planck's constant (6.626×10^{-34} J·s), and the temperature T is in units of Kelvin.
From this equation it is possible to show that the wavelength where the power is highest is given by $\lambda_{peak} = hc/(2.82\ kT)$



λ_{peak} = constant / T

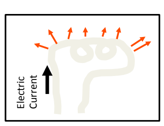
Black body spectrum at different temperatures



T increases - Power at all λ increases
- Proportionally more power at shorter λ
- λ_{peak} shifts to shorter λ ($\propto 1/T$)

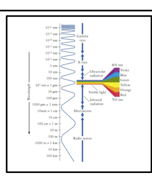
Why are light bulbs inefficient?

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



An efficient light bulb:

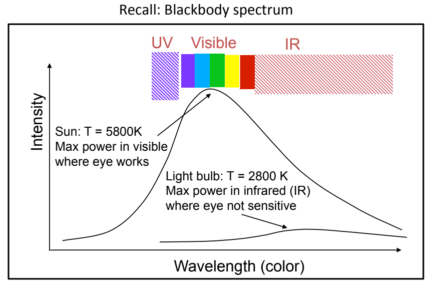
Electrical power in → 100% conversion → EM energy at visible λ



- But.....visible light is only a very small part of the EM spectrum
- Only 18% EM radiation from bulb is visible
- Rest is IR radiation (heat)
- Go to the blackbody spectrum simulation

Why are light bulbs inefficient?

Recall: Blackbody spectrum



Higher temperature
- More power ($\propto T^4$)
- Peak power at shorter wavelengths

How do could you make light bulbs more efficient?

Back to light bulbs.

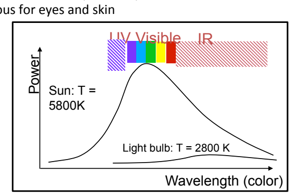
What would the ideal temperature be for a bulb filament?

a. Temp of standard bulb filament (2800 K).
b. Temp of the sun (5800 K).
c. Hotter than the sun.

Back to light bulbs.

What would the ideal temperature be for a bulb filament?

- At temperature of sun, λ_{peak} is in the visible, so the fraction of power emitted at visible wavelengths is maximized.
  - Max. visible light per watt of electrical power used
- At lower temp than sun too much power is wasted as IR radiation (heat)
- At higher temp than sun too much power is produced in the UV – also invisible and dangerous for eyes and skin



Note: Overall much more power in Sun that Light bulb too!

How can we improve light bulb efficiency?

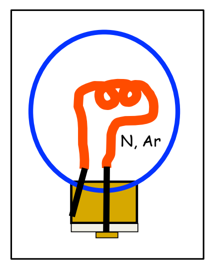
If hotter is better, why are filaments in standard bulb not heated to 5800 K?

a. because they melt if heated up any hotter
b. because they vaporize if heated up any hotter
c. because they oxidize ("burn up") if heated any hotter
d. would be too expensive to build

How can we improve light bulb efficiency?

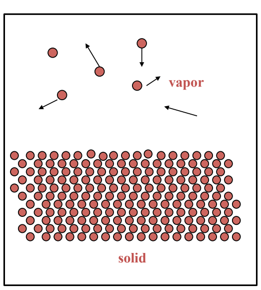
Solution to the "burning up" problem:

- Put the filament inside a bulb that has no oxygen
- Fill bulb with an inert gas like pure nitrogen or argon



What is sublimation?

Sublimation - direct solid to gas transition
- no liquid phase involved



Examples:
- Cold dry sunny day in Boulder - snow vanishes before melting
- "Dry ice" → carbon dioxide gas

Rate of sublimation increases rapidly with temperature of solid

How can we improve light bulb efficiency?

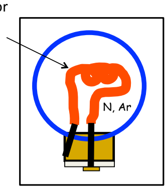
So, if we increase the filament temperature:

⇒ more visible light, better efficiency.
⇒ faster sublimation, shorter lifetime.

Filament temperature is a trade off between efficiency (<20%) and lifetime

Tungsten used for filament – low sublimation rate

- Eventually the filament sublimates away. You can see this in old light bulbs, where black stuff collects on the glass.



light bulb efficiency and lifetime?

The power company's generator is malfunctioning and so it provides 130 V electricity to your house, rather than the usual 120 V. As you will learn later in the course, this means that there is more electrical power going into all your light bulbs, and so they run hotter.

What are the implications of this?

Your light bulbs now:

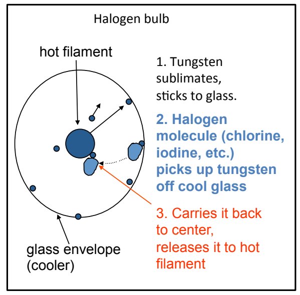
a. Produce more light, are redder in color, are more efficient, last longer.
b. Produce more light, are whiter, are more efficient, don't last as long.
c. Produce less light, are redder in color, are less efficient, last longer.
d. Produce more light, are whiter, are less efficient, don't last as long.

How can you improve efficiency and/or lifetime?

1. "Extended life" bulbs.
   These have thicker filaments
   ⇒ run cooler, last longer.
   ⇒ BUT less efficient

2. Halogen lamps
   - Undo sublimation so they can run hotter and more efficiently
   - Even a couple 100 C make a big efficiency improvement

3. Ditch the hot filament and use different technology
   - Florescent lights (CFLs)
   - LEDs
   - see later in course / Phys1020

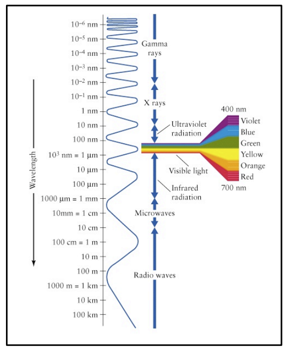


IR radiation: Thermal imaging

- Look at BB spectrum for a person (~ 313 K)
- No visible radiation emitted (too cold) – all in the IR
- Not detected by the eye, but detected by an IR (thermal imaging) camera

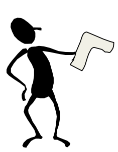
Thermal imaging – photography using non-visible EM radiation

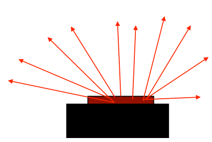
The electromagnetic spectrum



IR radiation

This remote temperature sensor works by measuring the infrared spectrum of the thing I point it at.



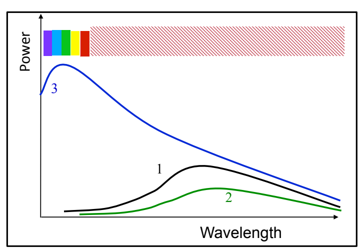


Try it out.

Now we put a piece of glass in the way.
What will temperature sensor read?

a. Same temperature,
b. Slightly less,
c. Much less,
d. Absolute zero

Identify spectrum of radiation given off by person (37 C) and a block of barely frozen ice (0 C).



a. 2 is person, 1 is ice,
b. 1 is person, 2 is ice,
c. None, because ice gives off no thermal radiation,
d. 1 is both ice and person because they are almost identical
e. 3 is person, one of the others is ice.