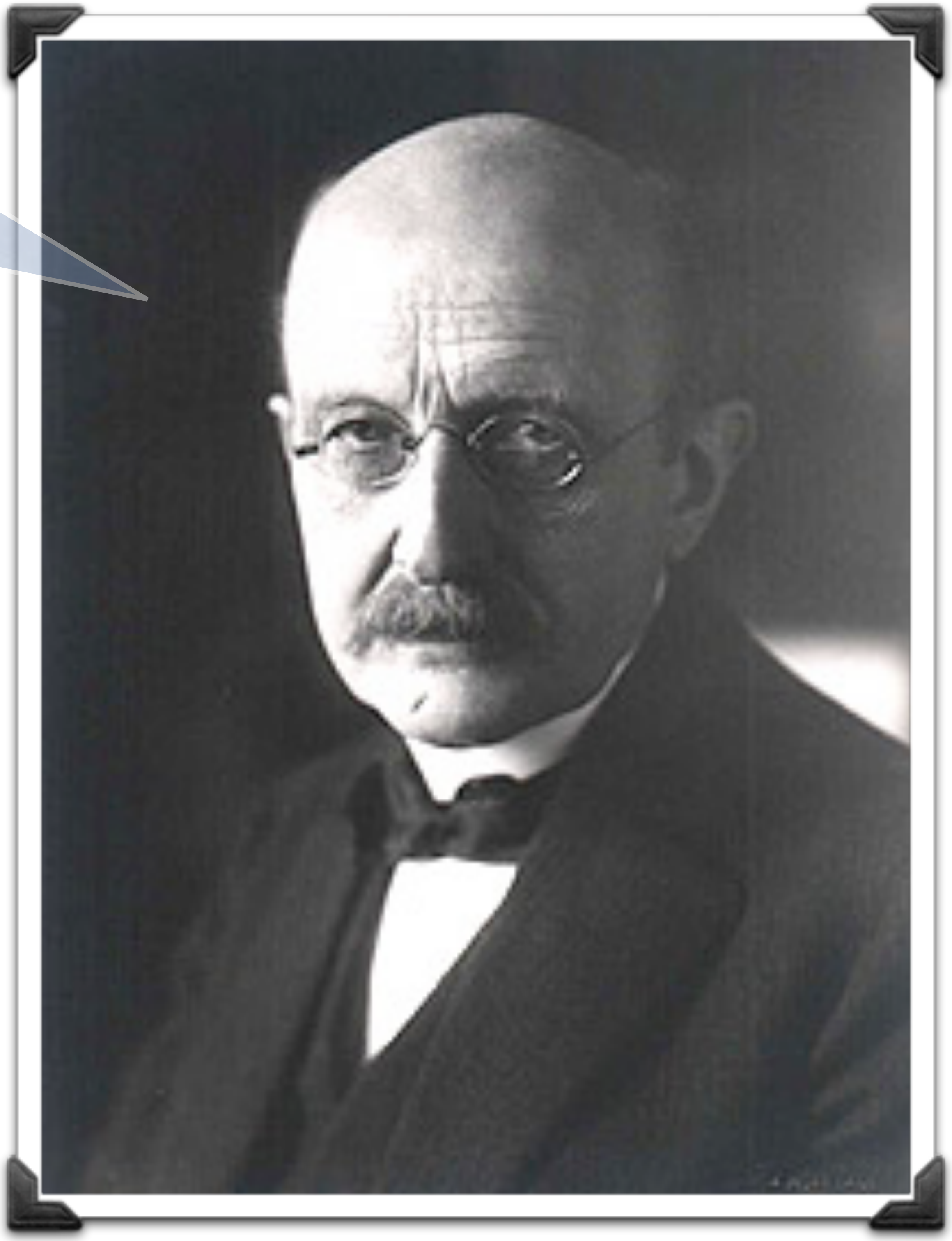
Welcome back to PHY 3305



Today's Lecture:

Blackbody Radiation

Photoelectric Effect

Max Plank

1858 - 1947

ANNOUNCEMENTS

- Reading Assignment:
  Chapter 3.3 - 3.6
- Problem set 4 is due Tuesday, Sept. 19th at 12:30 pm.
- Regrade for problem set 3 is due Tuesday, Sept 19th at 12:30 pm.
- Midterm exam 1 covering chapters 1-2 and related material will be in class on Thursday, Sept 21st. There will be a seating chart.S

REVIEW QUESTION 1

Firecracker 1 is 300 m from you. Firecracker 2 is 600 m from you in the same direction. You see both explode at the same time. Define event 1 to be "firecracker 1 explodes" and event 2 to be "firecracker 2 explodes". Does event 1 occur before, after or at the same time as event 2?

Event 1 occurs after event 2. The speed of light is the same for both event 1 and event 2 and event 2 occurs at a further distance than event 1. Hence, in order for me to observe the light from both events at the same time, event 2 must have occurred first.

REVIEW QUESTION 2

Your friend flies from Los Angeles to New York. He determines the distance using the tried-and-true method d = vt. You and your assistants on the ground measure the distance using meter sticks and surveying equipment. Who, if anyone, measures the proper length? Who, if anyone, measures the shorter distance?

You and your assistants measure proper length. Proper length is measured in the reference frame where the object (distance to New York) is at rest. The friend measures the shorter distance.

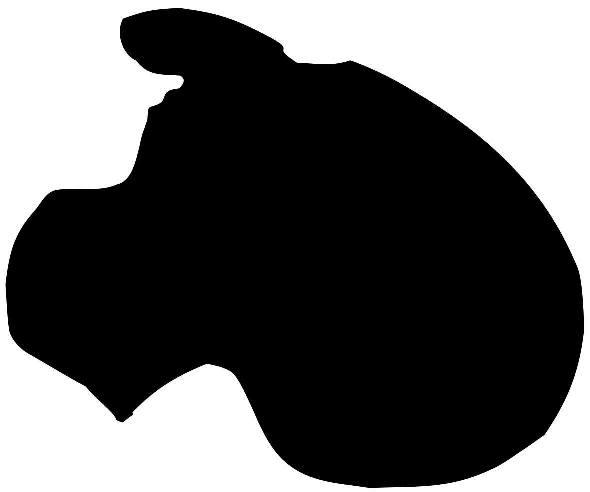
REVIEW QUESTION 3

Event A occurs at spacetime coordinates (300 m, 2 μs).
Event B occurs at spacetime coordinates (1200m, 6 μs).
Could A possibly be the cause of B?

Yes. No causal influence of any kind can travel faster than the speed of light, $c = 3.0 \times 10^8$ m/s. In this case, the causal influence moves at a speed of 2.25×10^8 m/s, which is slower than the speed of light.

$$\frac{(1200 - 300)\, m}{(6 - 2) \times 10^8\ s} = 2.25 \times 10^8\ m/s$$

What is a black body?



a) An object that does not emit or reflect optical radiation

b) An object painted black

c) An object that absorbs all radiation incident on it

d) An object that is not illuminated by any radiation (e.g. as in interstellar space)

STEFAN-BOLTZMAN LAW

A body that absorbs all radiation incident on it is called an **ideal blackbody**.

The empirical relationship between the power radiated by an ideal blackbody and the temperature was found in 1879 by Josef Stefan.

$$\boxed{I = \varepsilon\sigma T^4 \qquad \text{Stefan-Boltzman law}}$$

$\sigma = 5.67 \times 10^{-8}\ W/m^2\ K^4$, I = intensity = power/surface area

ε = emissivity = 1 for an ideal blackbody

This law was derived by Ludwig Boltzman in 1874. The derivation is problem 3.15 in your textbook.

Is the Earth considered a good example of a black body?

However, it is not an ideal blackbody. Temperatures of stars and planets can be estimated from a the blackbody curve.

a) Yes

b) Only during nighttime

c) No

Problem: How big is a star?

Measurement of the wavelength at which the spectral density distribution from a certain star indicates that the star's surface temperature is 3000K. If the star is also found to radiate 100 times the power radiated by the Sun, how big is the star? Express your answer in terms of r_{sun}. (Hint: The Sun's surface temperature is 5800 K.)

$$I = \sigma T^4$$

Surface Area Circle
$= 4\pi r^2$

$$I_{star} = \frac{P_{star}}{A_{star}} = \frac{100 P_{sun}}{4\pi r_{star}^2} = \sigma T_{star}^4$$

$$I_{sun} = \frac{P_{sun}}{A_{sun}} = \frac{P_{sun}}{4\pi r_{sun}^2} = \sigma T_{sun}^4$$

$$\frac{100P_{sun}}{4\pi r_{star}^2} = \sigma T_{star}^4$$

$$\frac{P_{sun}}{4\pi r_{sun}^2} = \sigma T_{sun}^4$$

Take the ratio:

$$\frac{\dfrac{\cancel{P_{sun}}}{\cancel{4\pi} r_{sun}^2}}{\dfrac{100\cancel{P_{sun}}}{\cancel{4\pi} r_{star}^2}} = \frac{\cancel{\sigma} T_{sun}^4}{\cancel{\sigma} T_{star}^4}$$

$$r_{star}^2 = 100 r_{sun}^2 \frac{T_{sun}^4}{T_{star}^4}$$

$$r_{star} = 10 r_{sun} \frac{T_{sun}^2}{T_{star}^2}$$

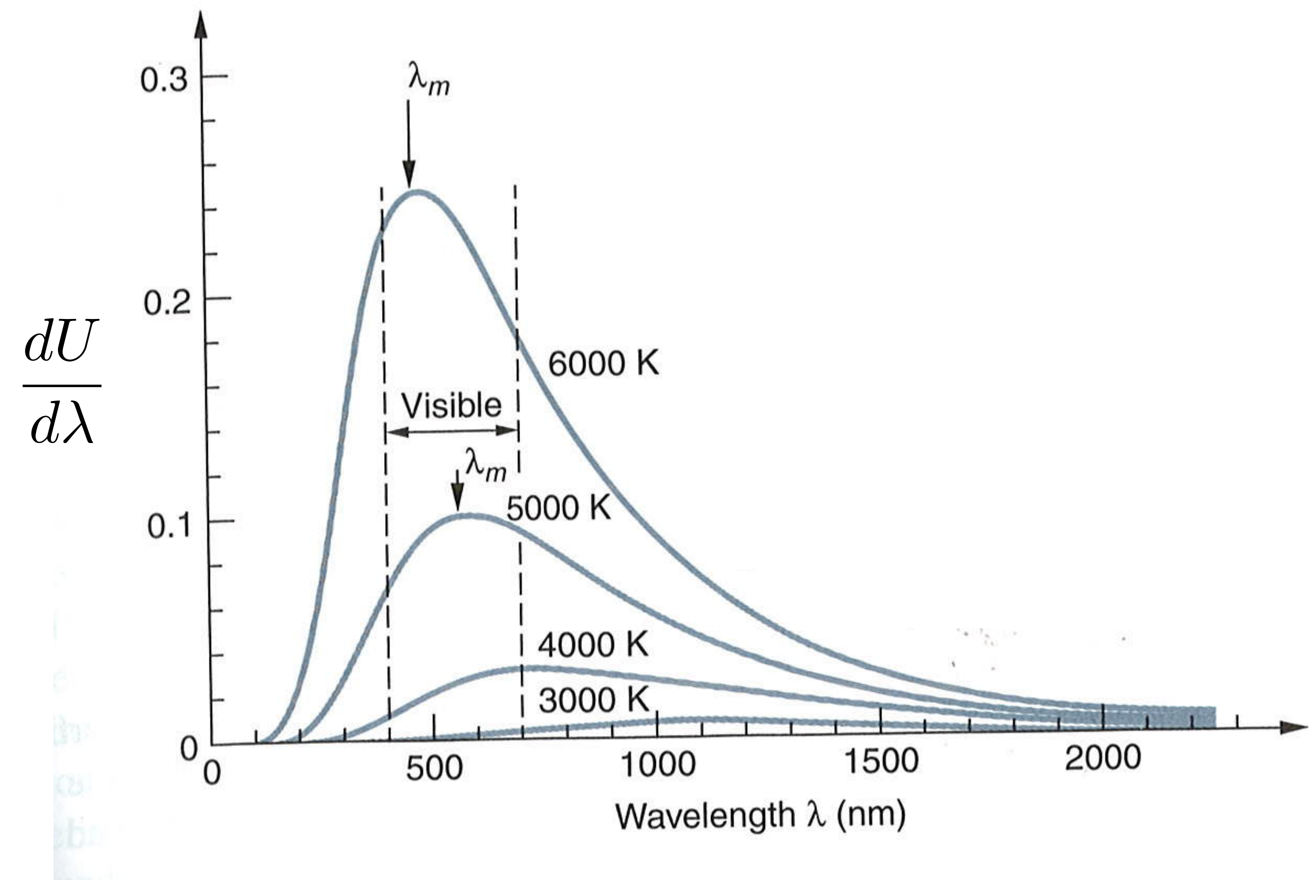
$$r_{star} = 10 r_{sun} \frac{5800^2}{3000^2} \longrightarrow \boxed{r_{star} = 37.4 r_{sun}}$$

Wien's Law:

The wavelength at which the blackbody distribution has it's maximum value varies inversely as temperature.

$$\lambda_{max} \propto \frac{1}{T}$$

$$\boxed{\lambda T = 2.898 \times 10^{-3} m \cdot K}$$



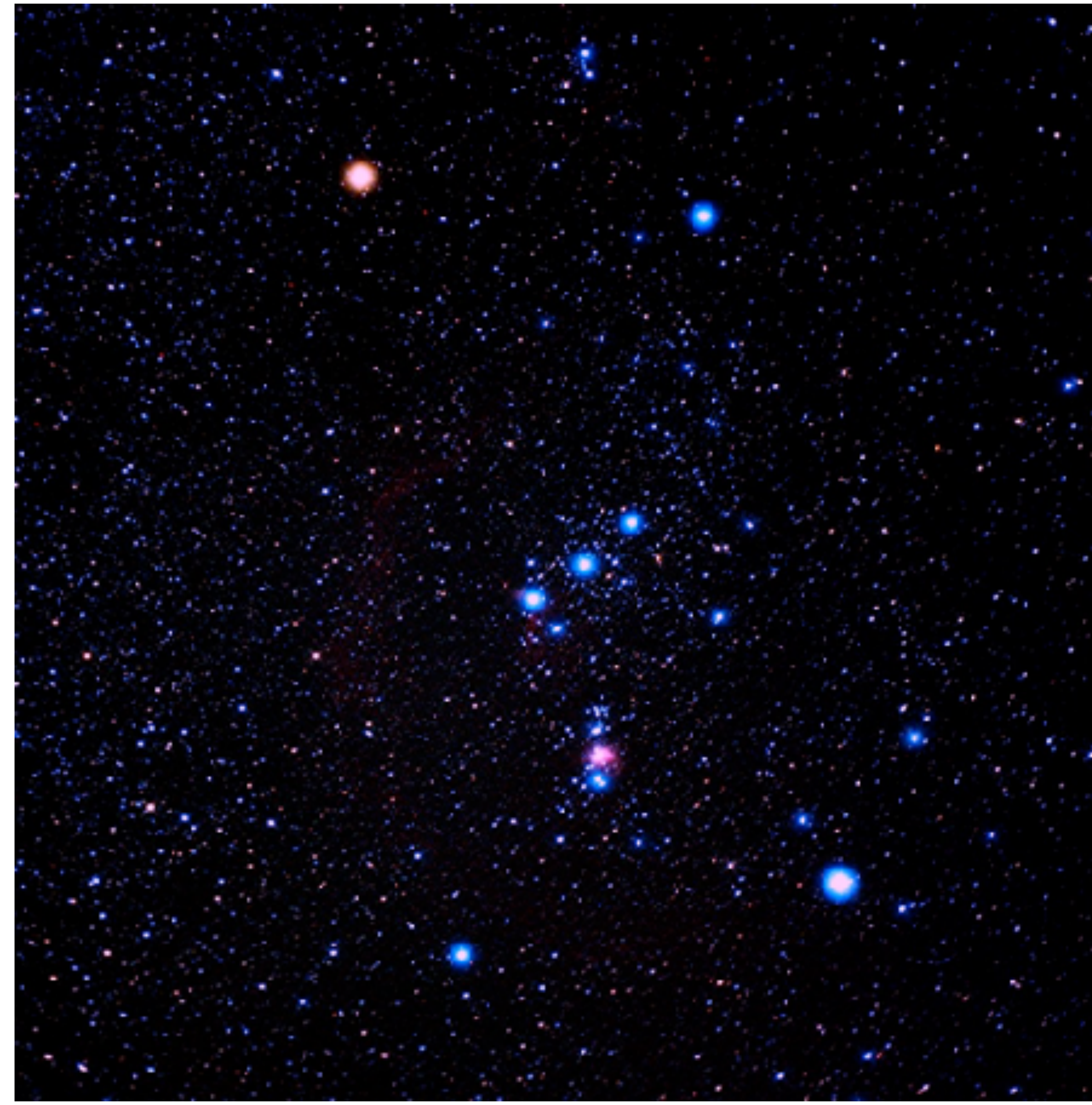
The derivation of Wien's Law is problem 3.14 in your textbook.

Also, the derivation of dU/dλ from dU/df is problem 3.13 in your textbook.

The constellation Orion has two well known stars - Betelgeuse and Rigel.

Betelgeuse appears red.

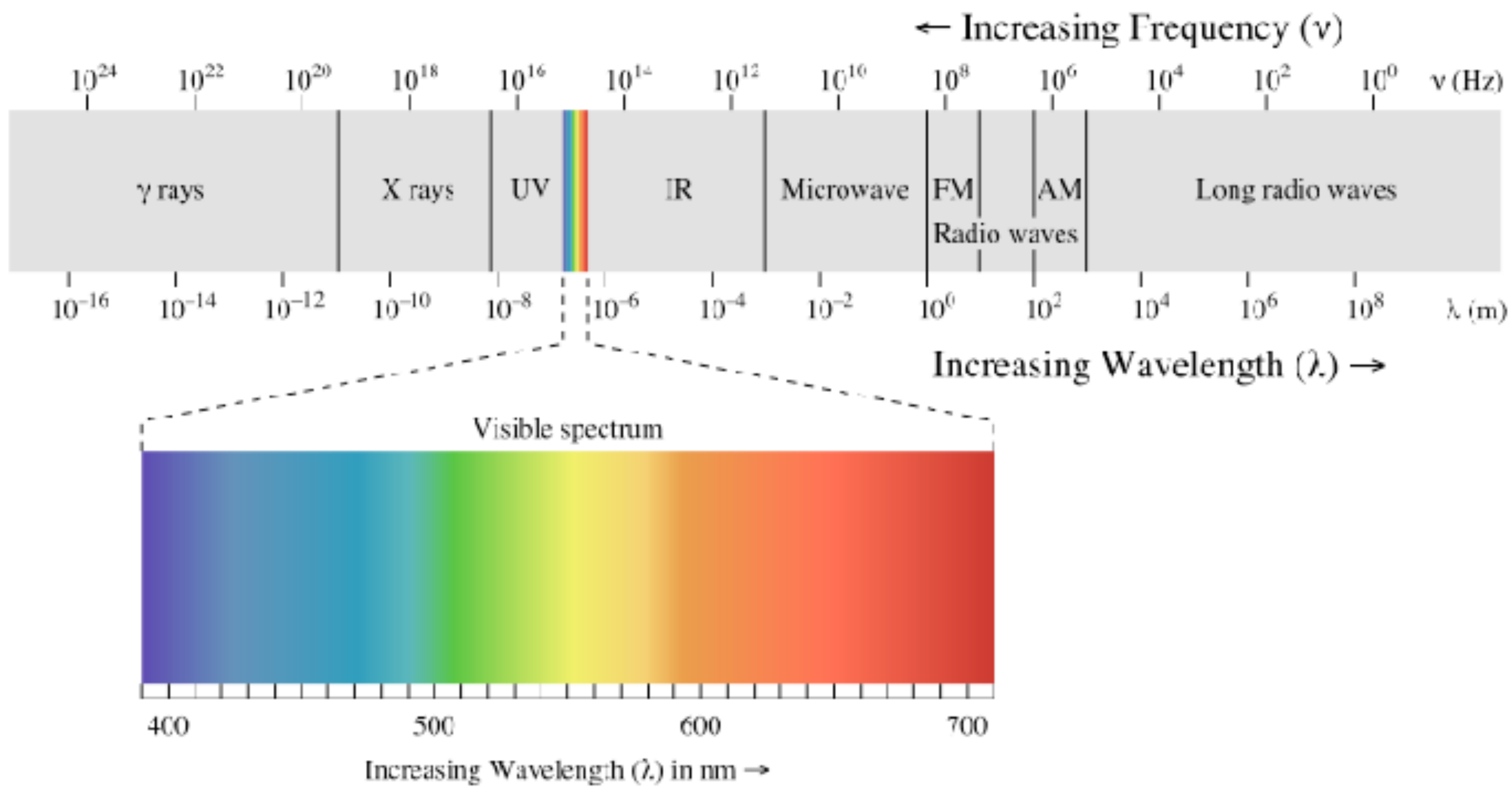
Rigel appears blue-whitish.



Which has the greater surface temperature?

Remember, as the temperature increases the wavelength decreases.

$$\lambda_{max} \propto \frac{1}{T}$$



CONSTELLATION ORION

Betelgeuse has a surface temperature of 3600 K and Rigel has a surface temperature of 13,000 K. Treat both stars as blackbodies and calculate the peak of their spectrums.

Betelgeuse:

$$\lambda_{max} = \frac{2.898 \times 10^{-3} m \cdot K}{3600K} = 8.05 \times 10^{-7} m = 805nm$$

infared

Rigel:

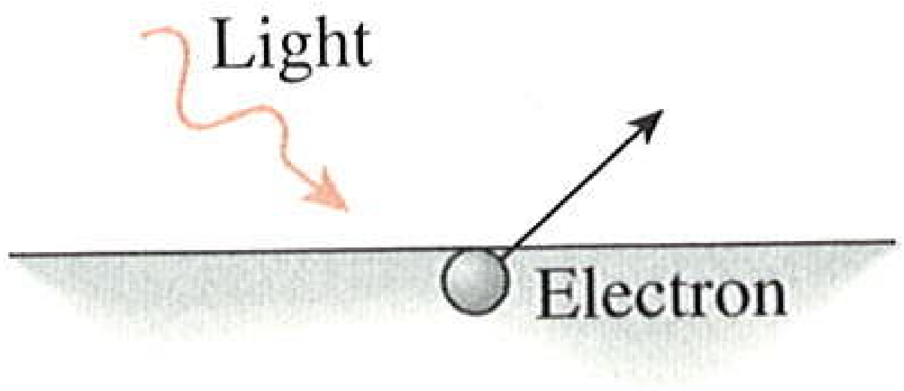
$$\lambda_{max} = \frac{2.898 \times 10^{-3} m \cdot K}{13,000K} = 2.23 \times 10^{-7} m = 223nm$$

ultraviolet

Video Lecture:

THE QUANTIZATION OF RADIATION: PHOTOELECTRIC EFFECT

What is the photoelectric effect?



Electrons are emitted from matter as a consequence of their absorption of energy from visible or ultraviolet radiation.

First observed by Heinrich Hertz in the 1880s.

"light producing a flow of electricity"

Heinrich Hertz
1857-1894 (yes, that Hz!)

Video Lecture:

Work Function:

The work function (φ) is the minimum amount of energy needed to strip the electron from the metal.

$$KE_{max} = hf - \phi$$

Kinetic energy of the electron.

Experimentally, we can determine φ of a metal by setting the voltage such that the current just drops to zero.

$$KE_{max} = eV_0$$

Thus, the work function can be determined by

$$\phi = hf - eV_0$$

A surface of zinc having a work function of 4.3 eV is illuminated by light with a wavelength of 200 nm. What is the maximum kinetic energy of the emitted photoelectrons?

$$KE_{max} = hf - \phi$$

$$KE_{max} = \frac{hc}{\lambda} - \phi$$

$$= \frac{1240\ eV \cdot nm}{200\ nm} - 4.3\ eV$$

$$\boxed{KE = 1.9\ eV}$$

Light of wavelength 400 nm is incident upon lithium (φ = 2.93 eV).

a) Calculate the photon energy of the light.

$$E = hf = \frac{hc}{\lambda} = \frac{1240 eV \cdot nm}{400 nm}$$

$$\boxed{E = 3.10\ eV}$$

b) Calculate the stopping potential.

$$eV_0 = hf - \phi = \frac{hc}{\lambda} - \phi$$

$$= \frac{1240\ eV \cdot nm}{400\ nm} - 2.93\ eV$$

$$\boxed{V_0 = 0.17\ V}$$

The work function of metal A is 3.0 eV. Metals B and C have work functions of 4.0 eV and 5.0 eV, respectively. Ultraviolet light is shined on all three metals, creating photoelectrons. Rank in order, from largest to smallest, the stopping potentials for A, B and C.

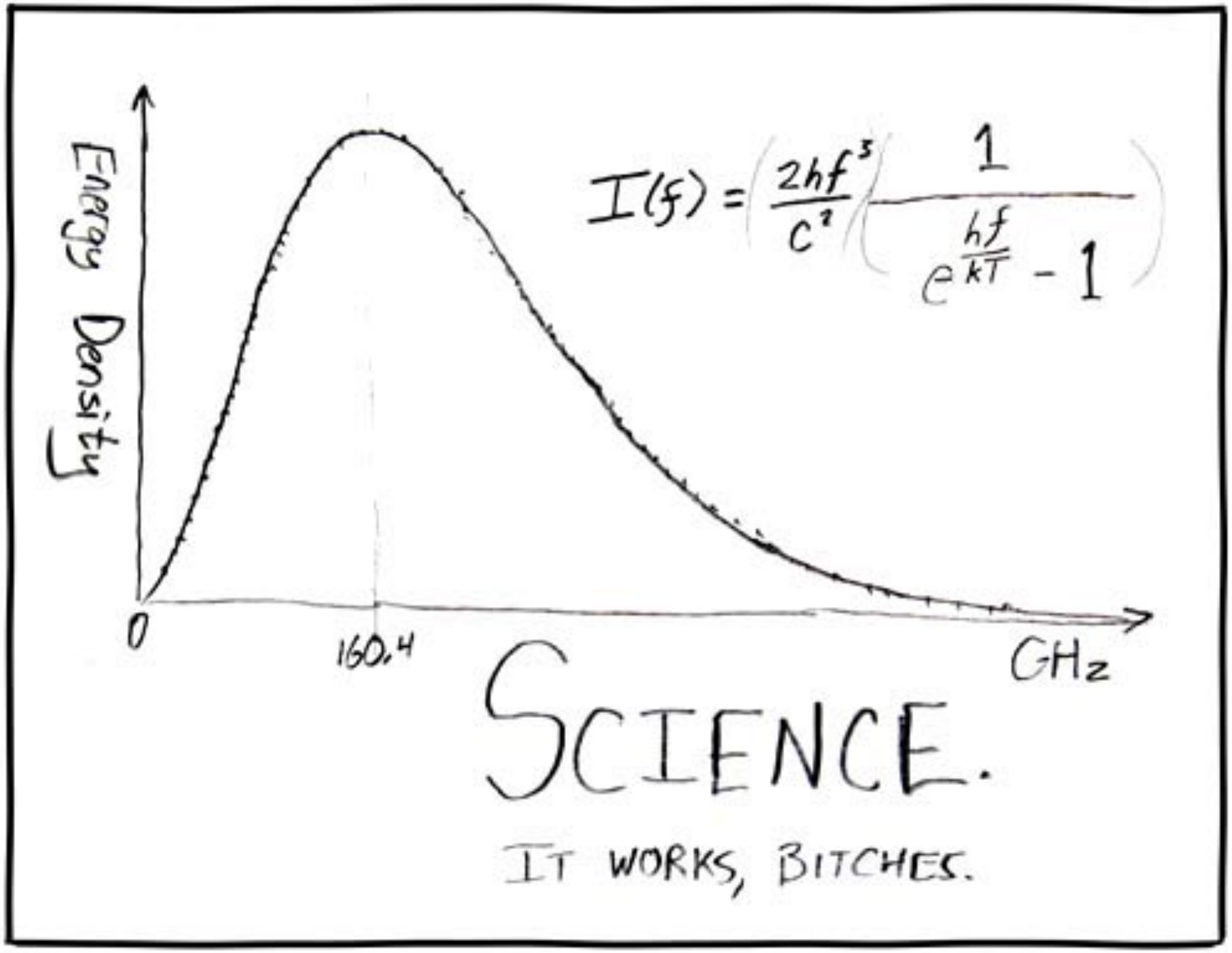
Answer: $\varphi_A > \varphi_B > \varphi_C$. For a given wavelength of light, electron are ejected with more kinetic energy from metals with smaller work functions because it takes less energy to liberate an electron. Faster electrons need a larger negative voltage to stop them.

$$KE_{max} = hf + \phi \qquad KE_{max} = eV_0 \longrightarrow \phi = hf - eV_0$$

LIGHT AS PARTICLES

- Blackbody Radiation
  - If light were a wave, we would expect the spectral density to continuously increase as a function of frequency.
  - Plank proposes that the average energy of a given wave is discrete - not continuous as in classical theory.
- Photoelectric Effect
  - If light were a wave, it should be able to eject electrons at any wavelength. There should be considerable lag time between the wave hitting the metal and the ejection of electrons. Also, increasing the intensity at any frequency should make the electrons more energetic.
  - Einstein proposes that light behaves as a collection of particles called photons.

The End (for today)!



https://xkcd.com/54/