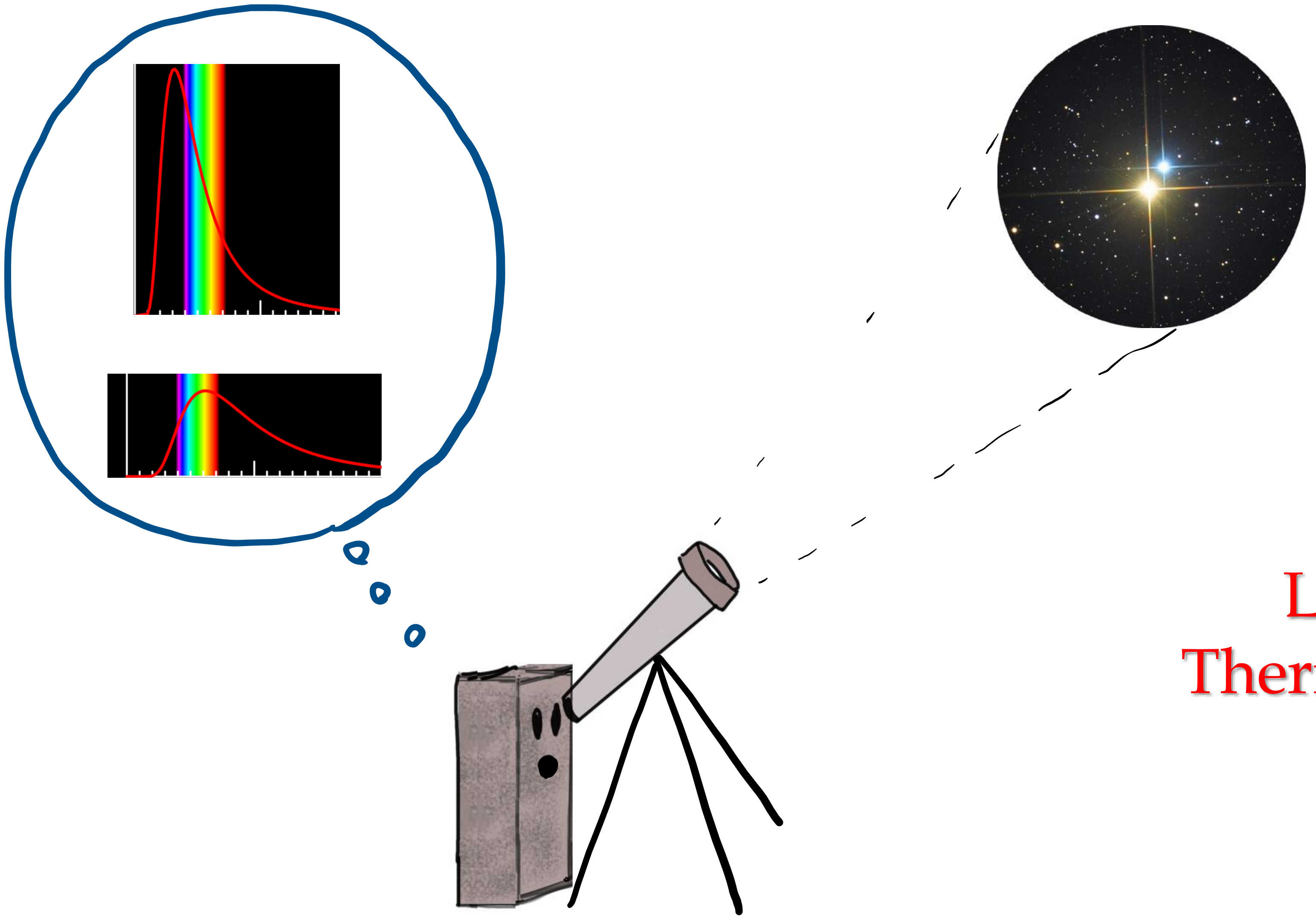
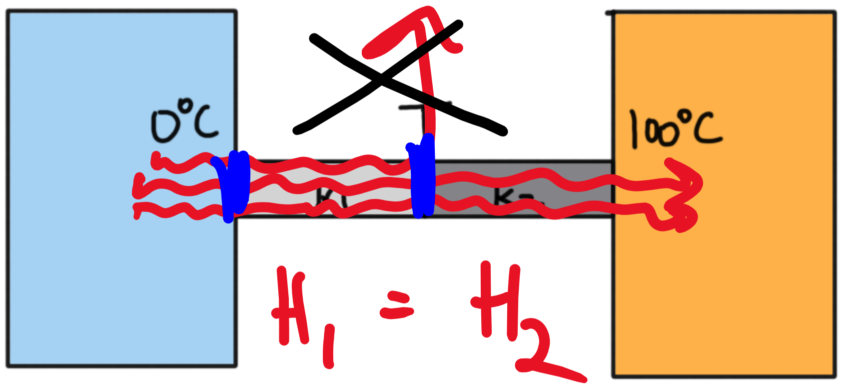


# Lecture 12.
# Thermal radiation

# Last Time




1) $\boxed{H = k A \frac{T_H - T_C}{L}}$

? $\cancel{k = \frac{k_1 + k_2}{2}}$ $\cancel{k = \sqrt{k_1 k_2}}$

$\cancel{k = \frac{k_1 k_2}{k_1 + k_2}}$ ?

0 °C, always


100 °C, always

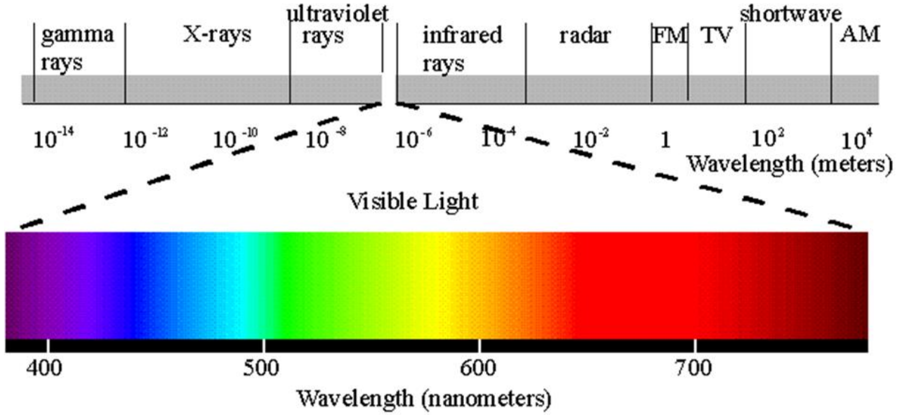
thermal reservoirs

2) $H = \frac{Q}{\Delta t}$ ← energy

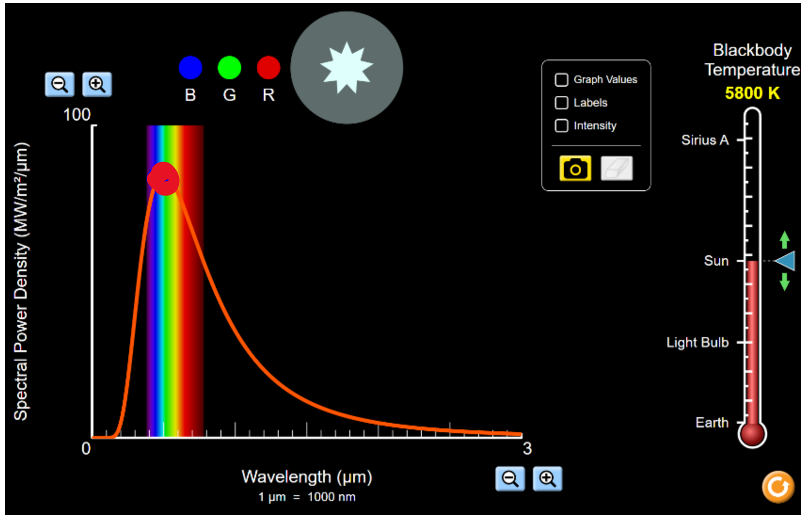
$\frac{k_1 A (\Delta T_1)}{L} = H_1 = H_2 = \frac{k_2 A \Delta T_2}{L}$ conserves

# Last Time

- Electromagnetic radiation: all wavelength



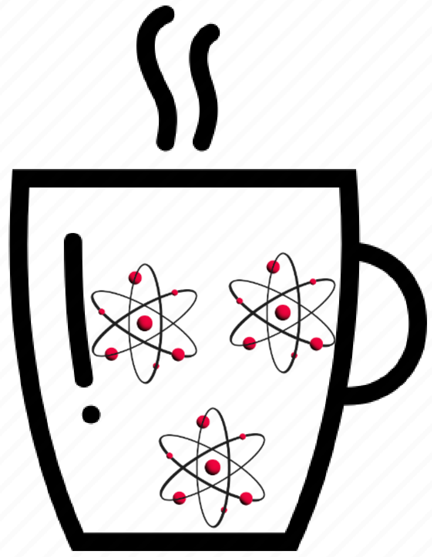

- Thermal radiation from an object comes in a set of wavelength, dominated by emission at $\lambda_{max}$



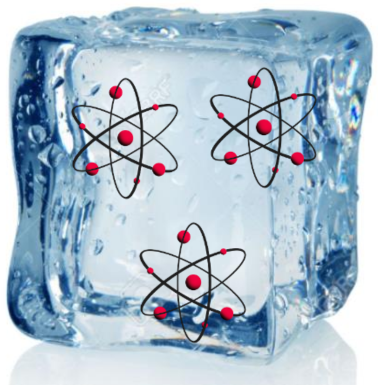

$\lambda_{max}$

- By changing $T$, we change the spectrum that an object emits

# Everything (that has T>0 K = *everything*) emits radiation!

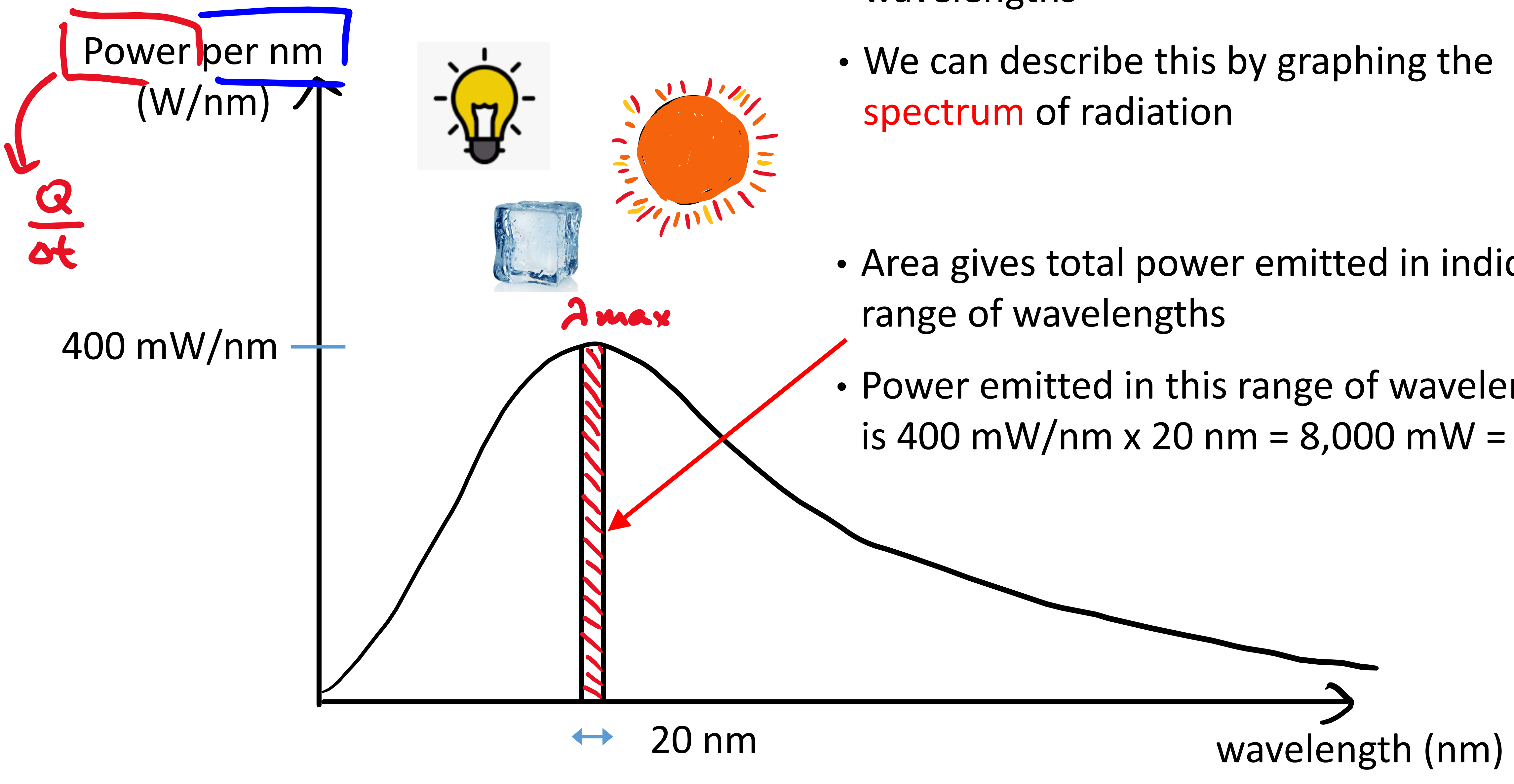


- "Thermal radiation" is made of electromagnetic waves
- "Every object is made of atoms, which are in perpetual motion"
- Atoms are made of electric charges (electrons & protons)
- Accelerating charges emit electromagnetic waves! (just take my word for it, or come to our more advanced courses)
- Everything emits thermal radiation.
- Also, everything absorbs thermal radiation…



- Note: higher T => more atomic motion => more thermal radiation!

# Thermal radiation from an object

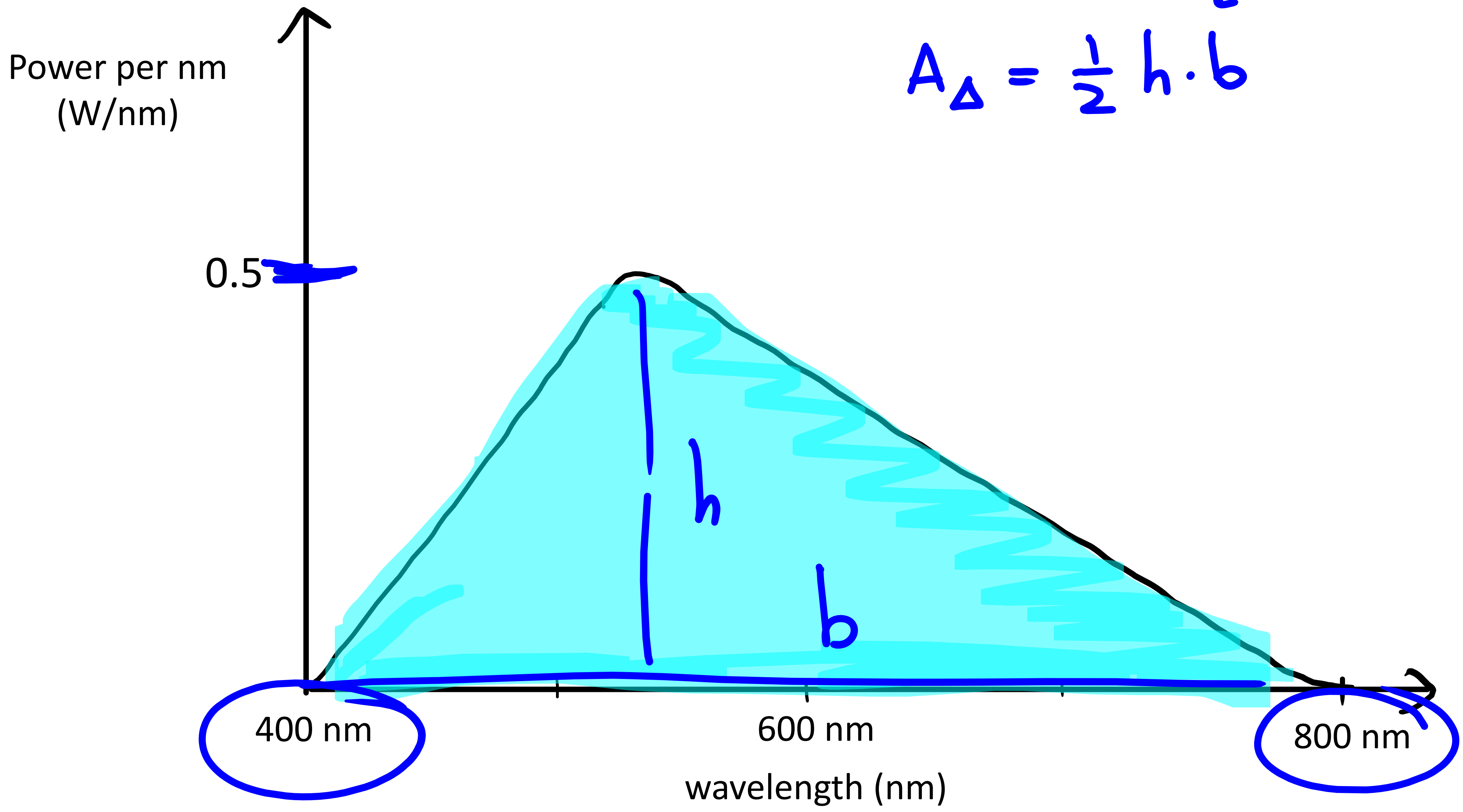



- Radiation from an object comes in a mix of wavelengths
- We can describe this by graphing the spectrum of radiation
- Area gives total power emitted in indicated range of wavelengths
- Power emitted in this range of wavelengths is 400 mW/nm x 20 nm = 8,000 mW = 8 W

Q: The spectrum for a certain lightbulb is shown. The total power of the bulb is closest to:

height → base

$A_{\Delta} = \frac{1}{2} h \cdot b$




A. 0.1 W

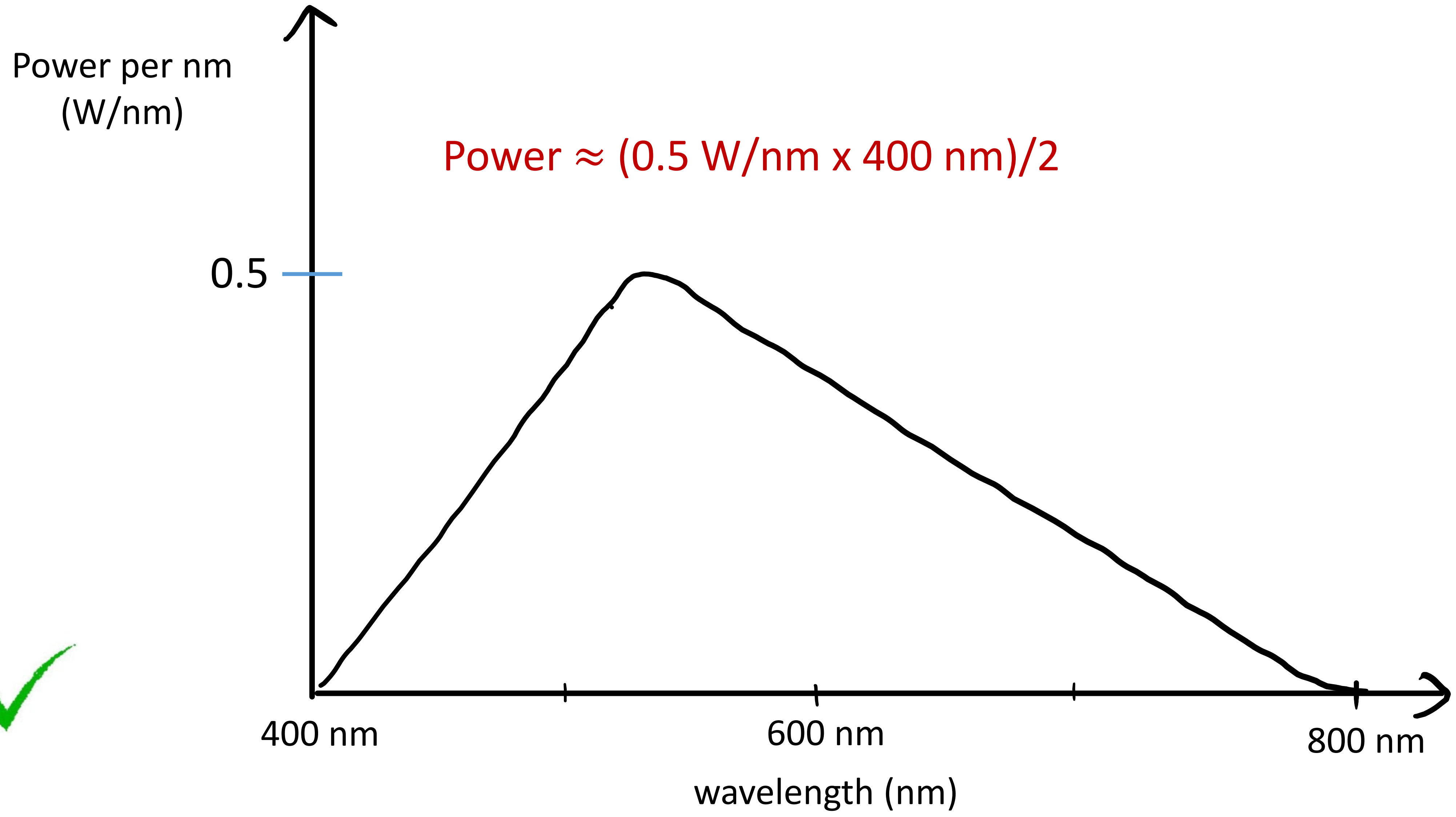
B. 1 W

C. 10 W

D. 100 W

E. 1000 W

Q: The spectrum for a certain lightbulb is shown. The total power of the bulb is closest to:



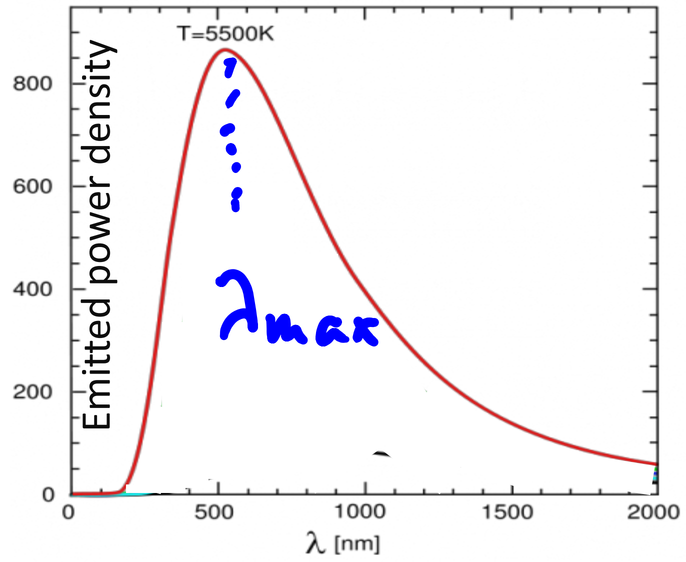

A. 0.1 W
B. 1 W
C. 10 W
D. 100 W ✓
E. 1000 W

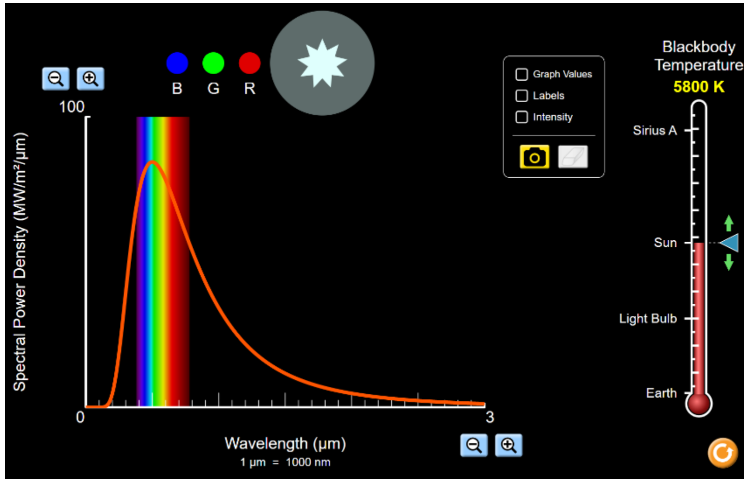
# Black-body Spectrum

- Black-body: An idealized object that perfectly absorbs and emits electromagnetic radiation at all frequencies.

- Its spectrum has a distinct shape, with a maximum at a certain wavelength $\lambda_{max}$. Radiation from an object is dominated by the waves with $\lambda \sim \lambda_{max}$.

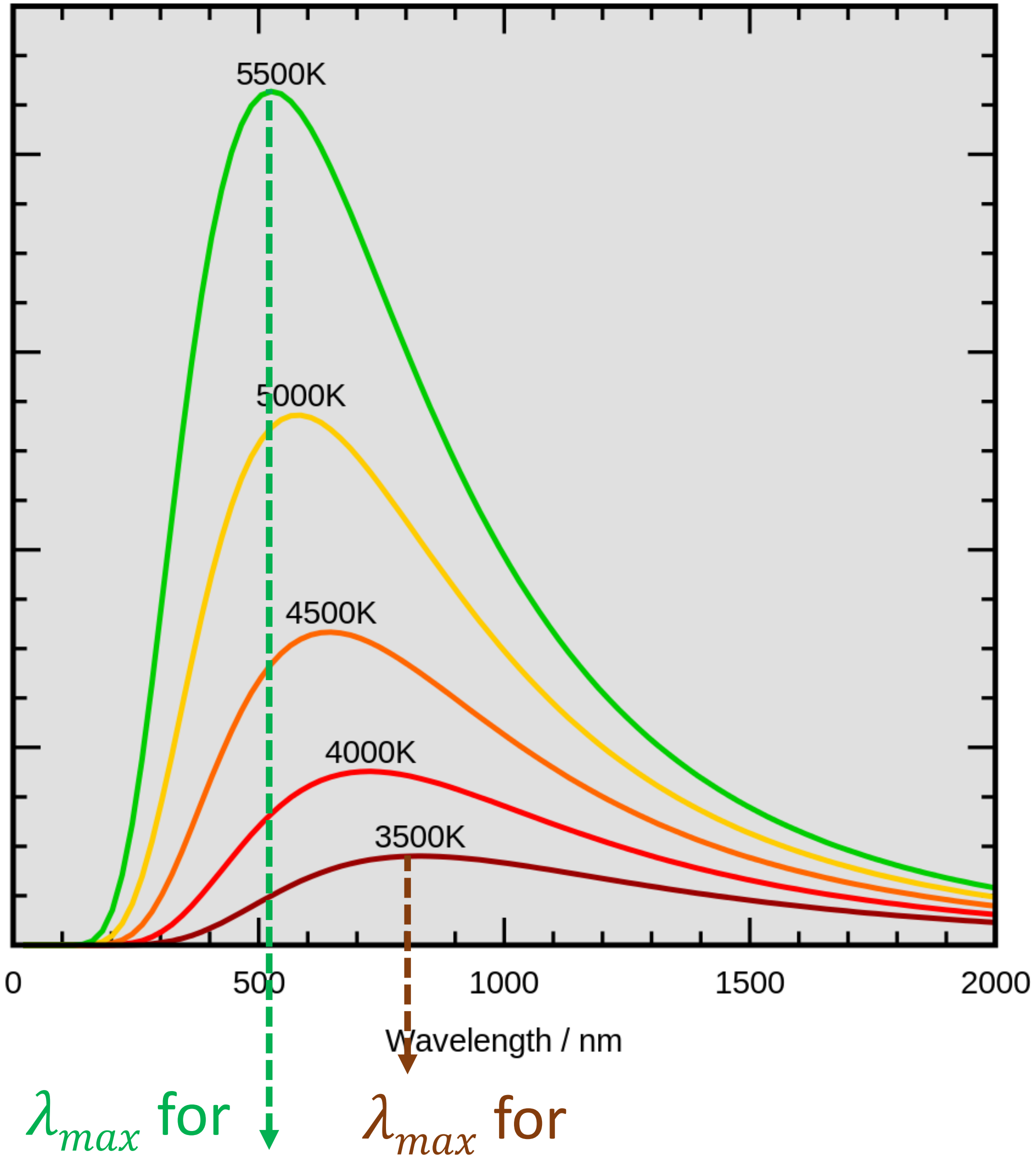
- We have seen in this simulation that the spectrum depends on the temperature of the object. Varying temperature will:
  - ➢ Shift the location of the peak, $\lambda_{max}$
  - ➢ Vary the height of the peak (intensity of radiation)




https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_en.html

# Wien Displacement Law




$\lambda_{max}$ for 5500 K

$\lambda_{max}$ for 3500 K

Wien's law:

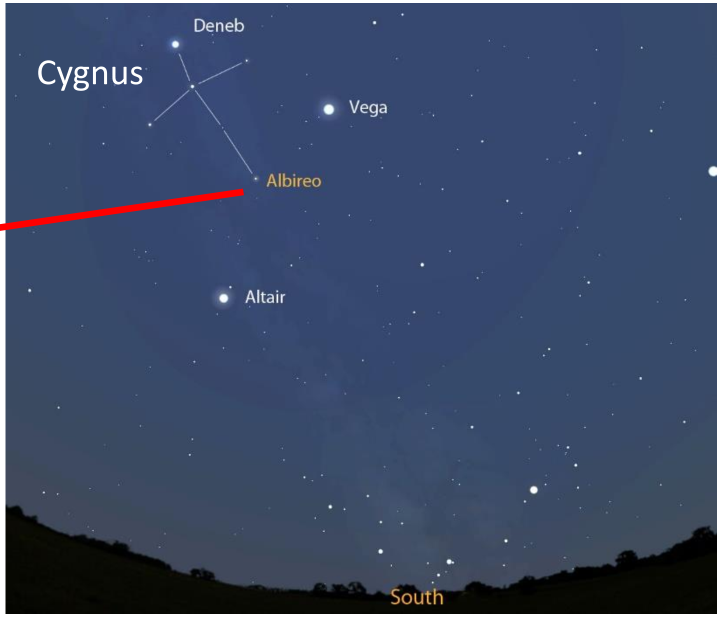
- Peak wavelength is inversely proportional to $T$

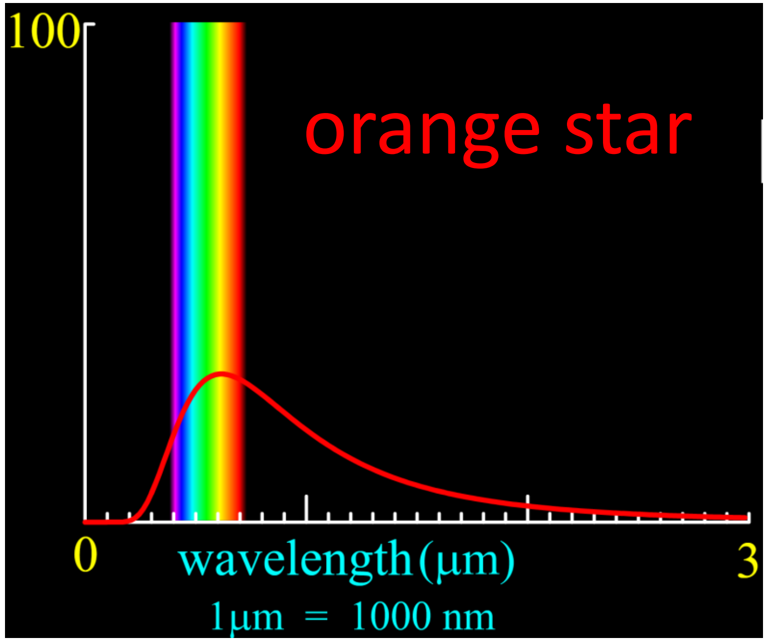
$nm = 10^{-9} m$

$$\boxed{\lambda_{max} = \frac{b}{T}}$$

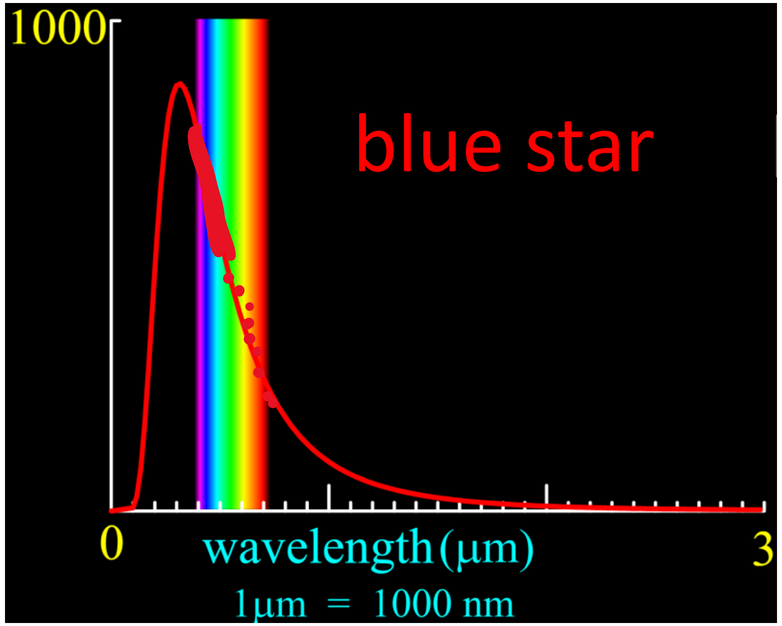
where $b = 2.9\ K \cdot mm$, $= 2.9\ K \cdot m \cdot 10^{-3}$
and $T$ is measured in Kelvin

- Sun: peak at ~ 500 nm (5700 K)
- Outer space: peak at ~ 1 mm (2.7 K)
  "cosmic microwave background"



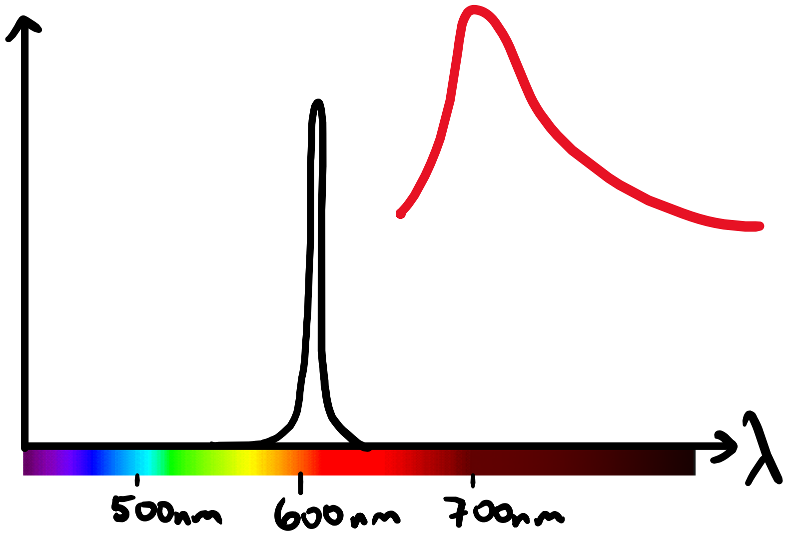

T ~ 4500 K



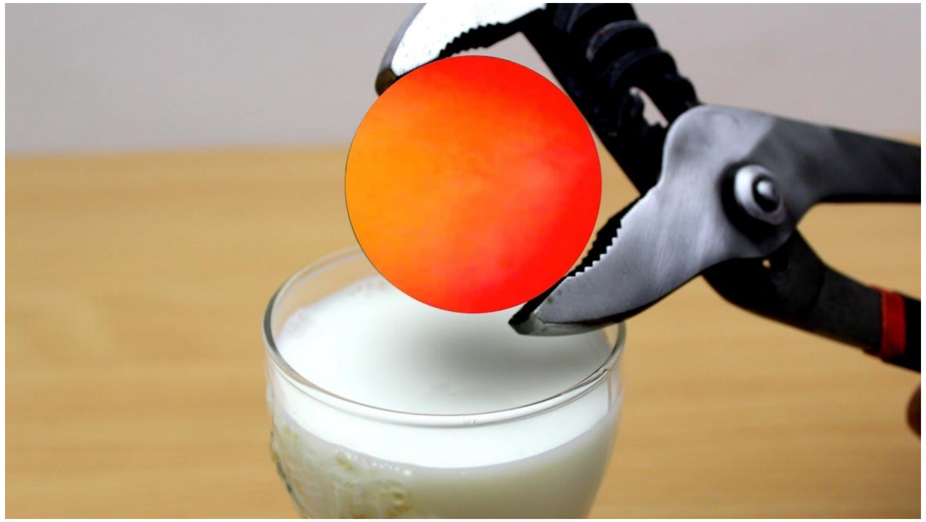

T ~ 12,000 K

# Q: Which graph best represents the spectrum of radiation from the red hot ball in the picture?

~~A.~~

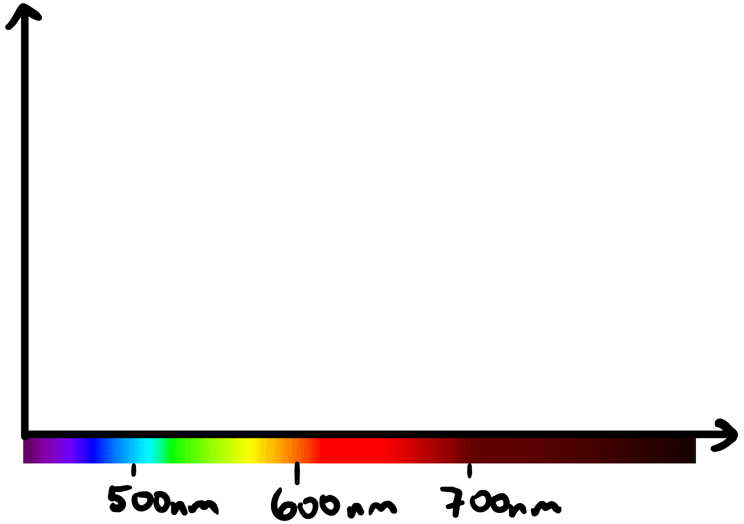



D. Smth else

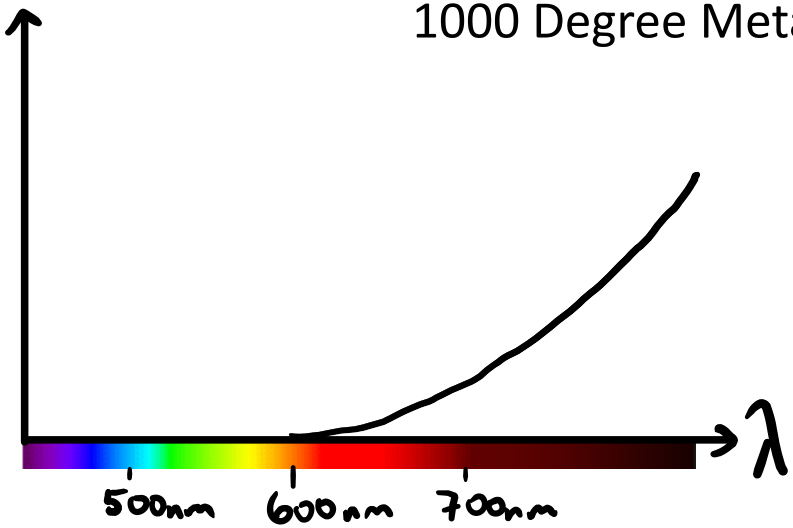


From Youtube:
1000 Degree Metal Ball vs Milk

B.



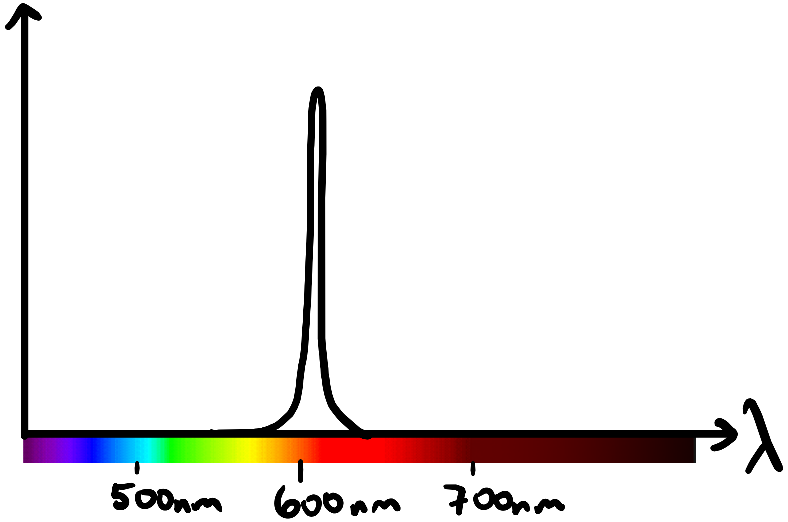

C.

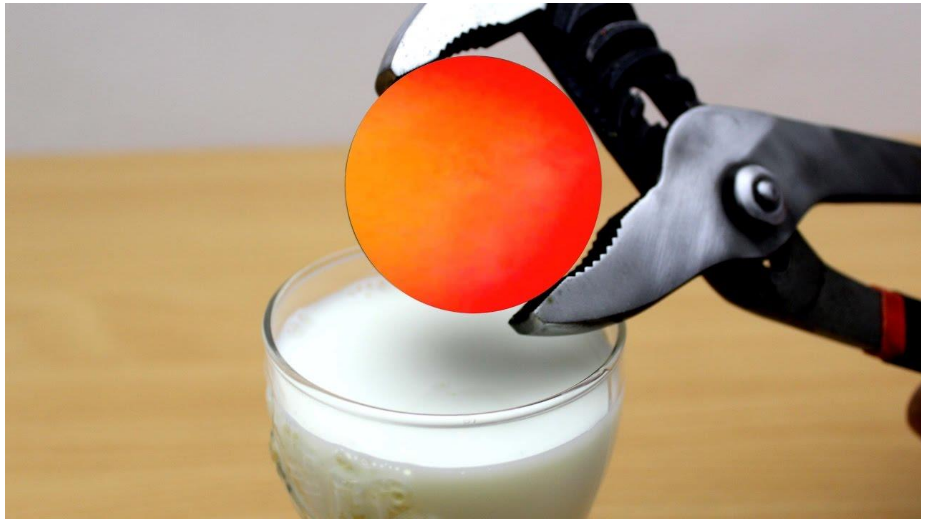


Q: Which graph best represents the spectrum of radiation from the red hot ball in the picture?

$$\lambda_{max} = \frac{b}{T} = \frac{2.9 \cdot 10^{-3}\ mK}{1273\ K} = 2280\ nm$$

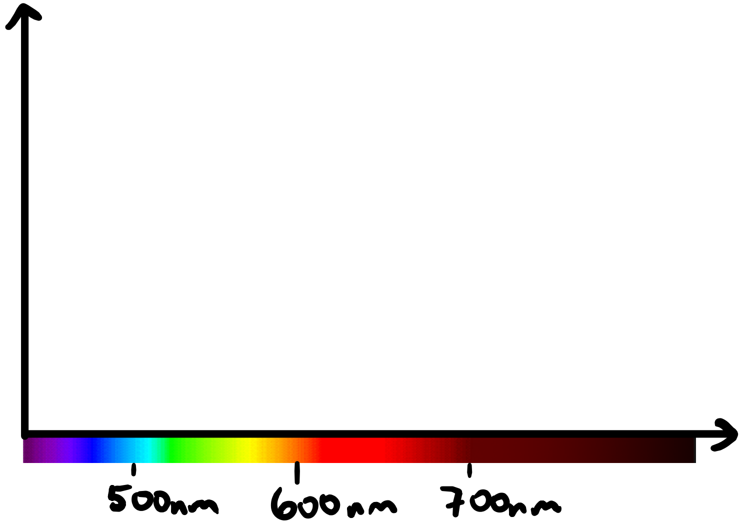
A.



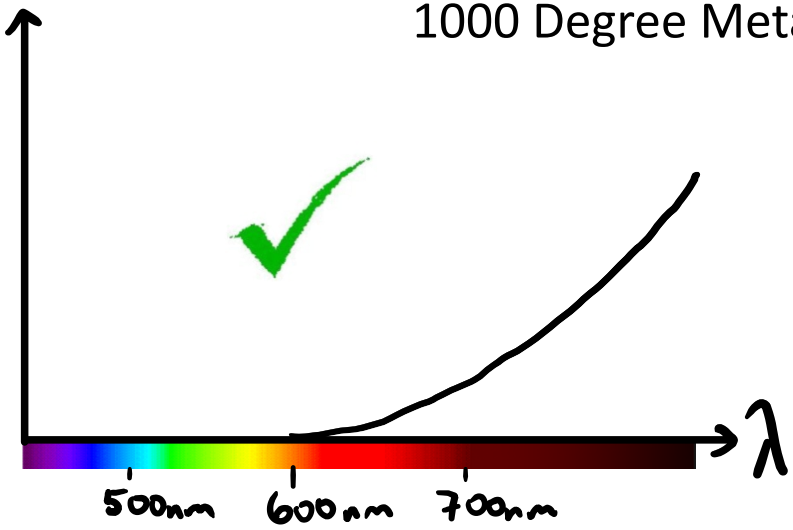



From Youtube:
1000 Degree Metal Ball vs Milk

B.




C.

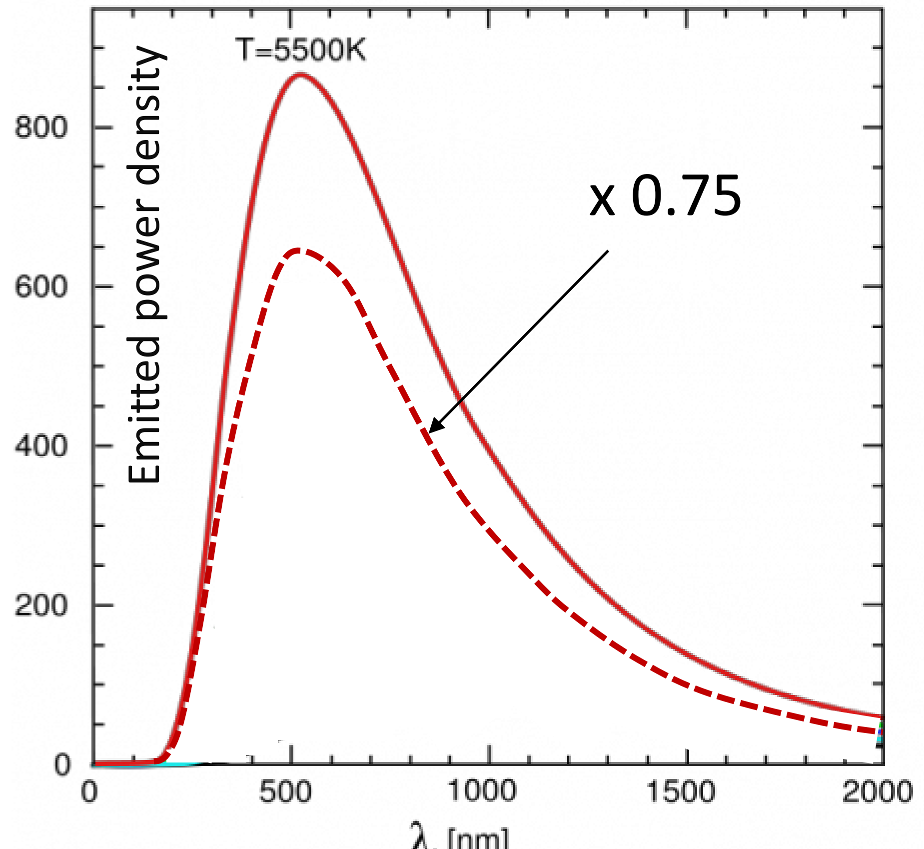


# Emissivity

- Black-body: perfect absorber and emitter: emits most thermal radiation for a given $T$
- We will use black-body radiation as an *idealized approximation* to model objects in the real world, from ice to hot cup of coffee to Sun.

- The difference between the ideal black-body and real-world objects is captured by objects' emissivity ($e$)

- In general, $e$ depends on the material properties but also on temperature and wavelength. Roughly, it is a number between 0 and 1, where
  - $e$ = 1 perfect absorber (black body)
  - $e$ = 0 perfect reflector (mirror)



Q: What does emissivity $e$ express?

A. How well an object emits radiation
B. How well an object absorbs radiation
C. How well an object absorbs and emits radiation
D. How well an object transmits radiation
E. None of the above

Q: What does emissivity $e$ express?

A. How well an object emits radiation

B. How well an object absorbs radiation

C. How well an object absorbs and emits radiation ✓

D. How well an object transmits radiation

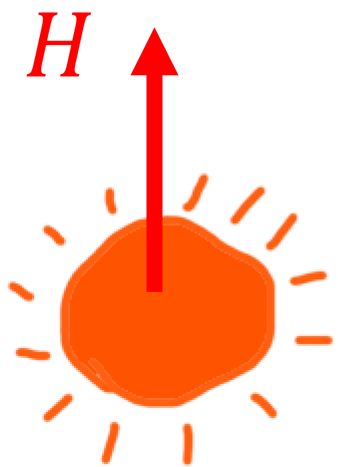
E. None of the above

*Emissivity captures how a real object is different from the ideal black-body in both absorptive and emittive properties. They always go together: an atom or a molecule first absorbs a portion of light, and then emits it, it does not keep light inside forever!*

*Note: A good absorber is also a good emitter, and the other way around!*

# Stefan–Boltzmann law

Stefan–Boltzmann Law:




- Total power from thermal radiation is proportional to $T^4$

$$\boxed{H = \frac{Q}{\Delta t} = Ae\sigma T^4}$$

- $A$ = surface area (an object emits / absorbs via surface)

"sigma"

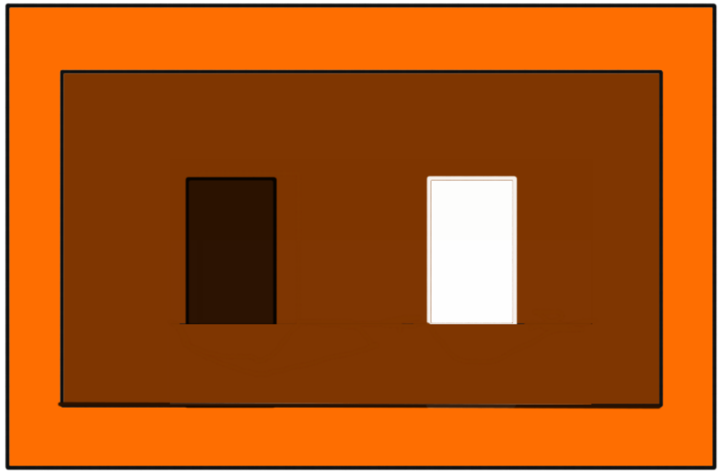
- $\sigma$ = $5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$ = Stefan-Boltzmann constant

- $e$ = emissivity

  - $e$ = 1 perfect absorber (black)
  - $e$ = 0 perfect reflector (mirror)

Q: A white object and a black object both sit in an oven. The oven and the objects are in equilibrium at 1500 degrees Celsius. We can say that the net heat current due to radiation, $(H_{\text{absorbed}} - H_{\text{emitted}})$ is

A. Larger for the white object
B. Larger for the black object
C. The same for both objects and greater than zero.
D. The same for both objects and equal to zero.
E. The same for both objects and less than zero.



$H_{in} = H_{out} \rightarrow H_{abs} = H_{emitted}$

Q: Assume that there are no conduction or convection effects. Which object is emitting more radiation?

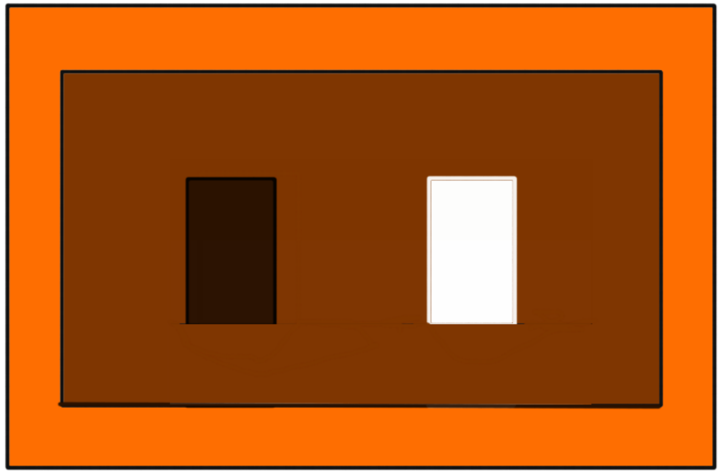
A. Black
B. White
C. Same

$e_b > e_w$

$$\boxed{H = Ae\sigma T^4}$$

Q: A white object and a black object both sit in an oven. The oven and the objects are in equilibrium at 1500 degrees Celsius. We can say that the net heat current due to radiation, $(H_{\text{absorbed}} - H_{\text{emitted}})$ is

A. Larger for the white object
B. Larger for the black object
C. The same for both objects and greater than zero. ✓
D. The same for both objects and equal to zero.
E. The same for both objects and less than zero.



Equilibrium, so uniform temperature and no net heat current $\Rightarrow H_{\text{absorbed}} = H_{\text{emitted}}$

Q: Assume that there are no conduction or convection effects. Which object is emitting more radiation?

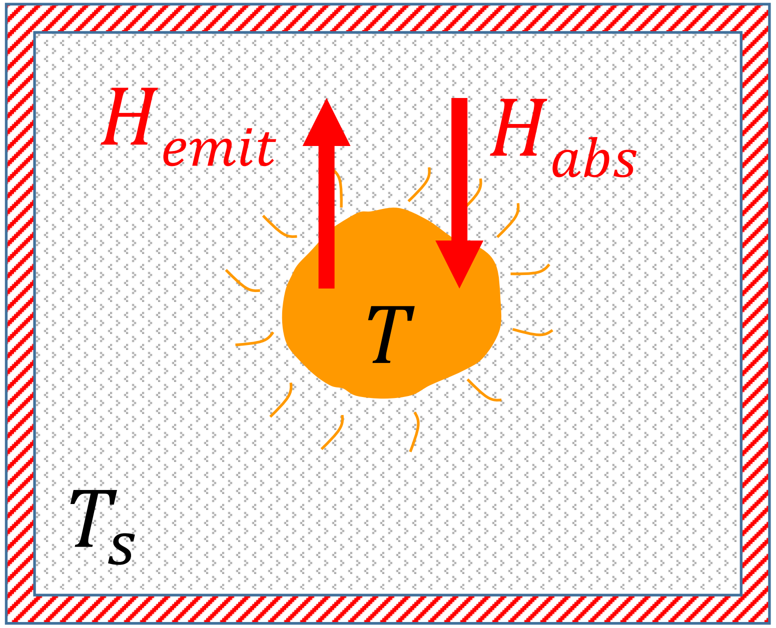
A. Black ✓
B. White
C. Same

black object has higher emissivity

Note that emissivity is greater for black object so it radiates more!
But it also absorbs more (thermal eq.).

$$\boxed{H = Ae\sigma T^4}$$

# Radiative heat exchange between an object and its environment




$$H_{net} = H_{emit} - H_{abs}$$

$$H_{emit} = Ae\sigma T^4 \qquad H_{abs} = ?$$

- Imagine an object has temp $T_s$ and is in equilibrium with box at temp $T_s$
- It emits $H_{emit} = Ae\sigma {T_s}^4$ and absorbs some $H_{abs}$ from the box
- These will be equal in equilibrium, so $H_{abs} = Ae\sigma {T_s}^4$

> A = surface area of object
> $e$ = emissivity of object
> $\sigma$ = Stefan-Boltzmann constant
> $T$ = temp of object
> $T_s$ = temp of surroundings

Area, emissivity & T of object

Temp of environment

$$\boxed{H_{net} = Ae\sigma(T^4 - T_s^4)}$$