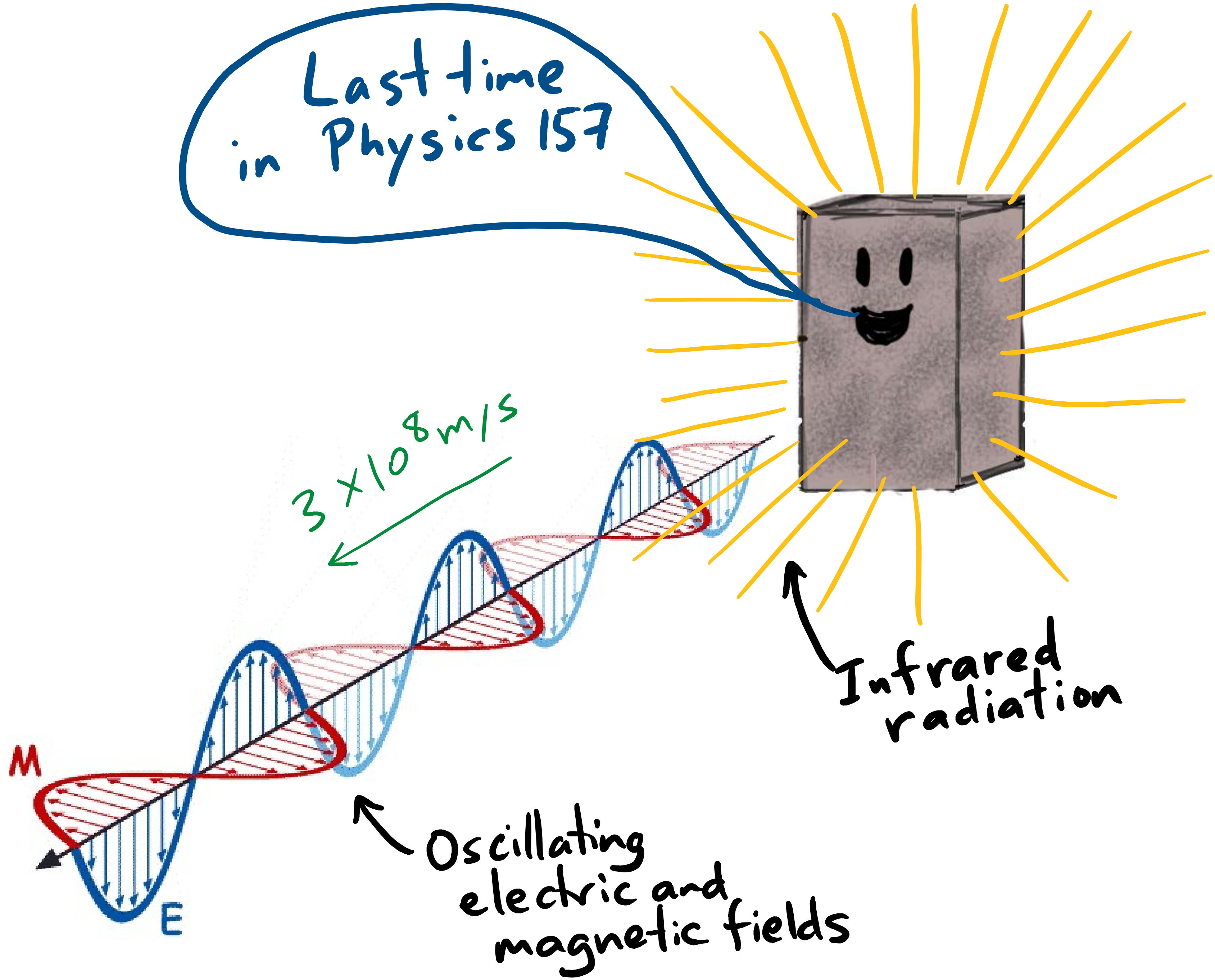
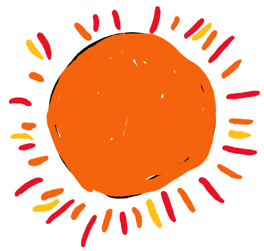
Learning Goals:

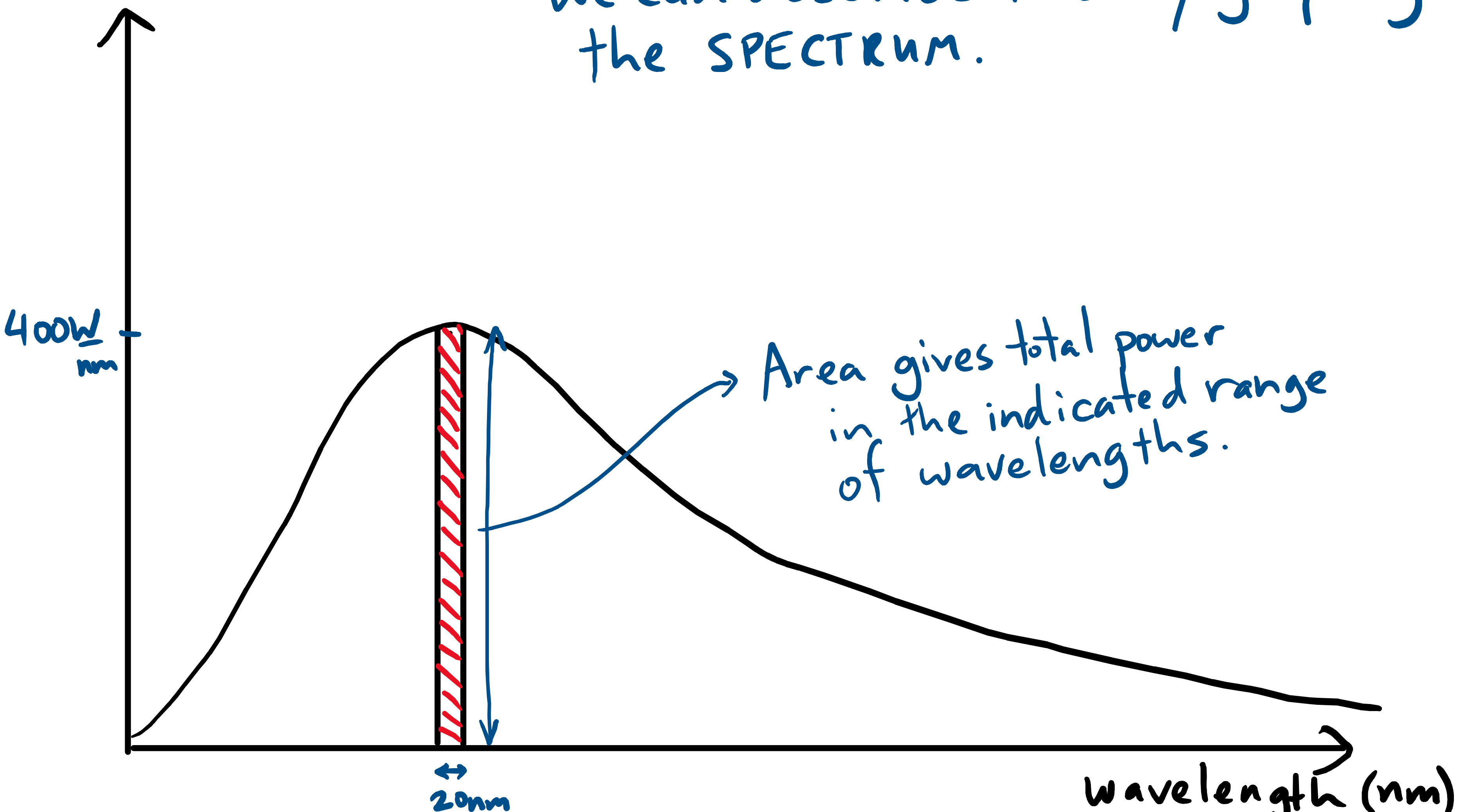
- Qualitatively describe the spectrum of thermal radiation and how this depends on temperature.
- Determine the temperature of an object using the peak wavelength for its thermal radiation
- Predict the total power of radiation from an object given its temperature, surface area, and emissivity
- Explain why the emissivity of an object is higher for objects that are better absorbers
- Argue that for a system whose temperatures are not changing, the heat current into any part equals the heat current out of that part
- Predict the surface temperature of an object give the heat current absorbed and/or heat currents from the interior


Last time in Physics 157
3 x10^8 m/s
Infrared radiation
M
E
Oscillating electric and magnetic fields



Radiation from an object comes in a mix of wavelengths.

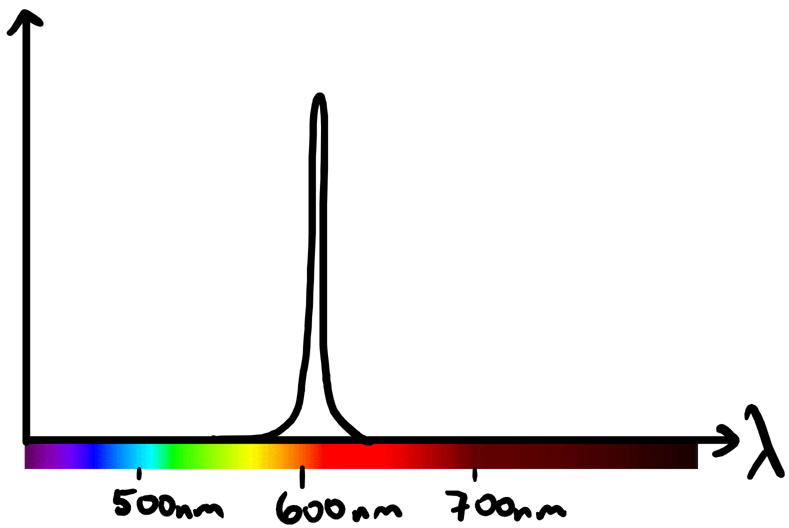
We can describe this by graphing the SPECTRUM.



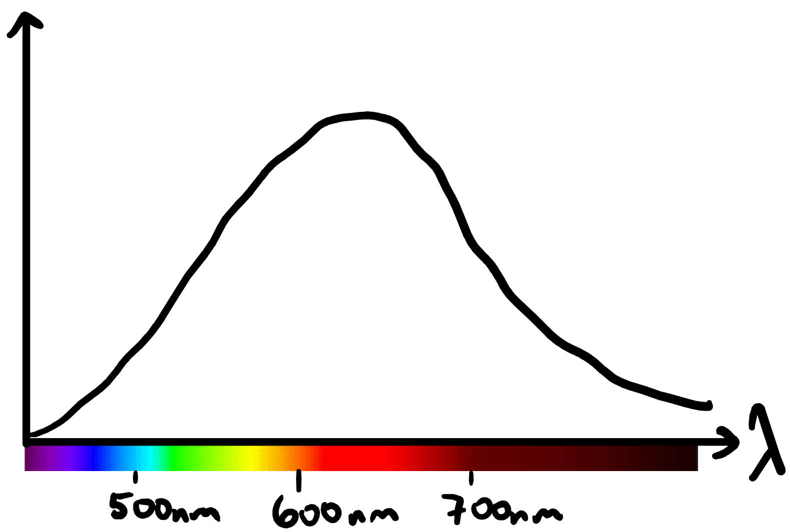
Which graph best represents the spectrum of radiation from the red hot ball in the picture?

from Youtube: 1000 Degree Metal Ball vs Milk

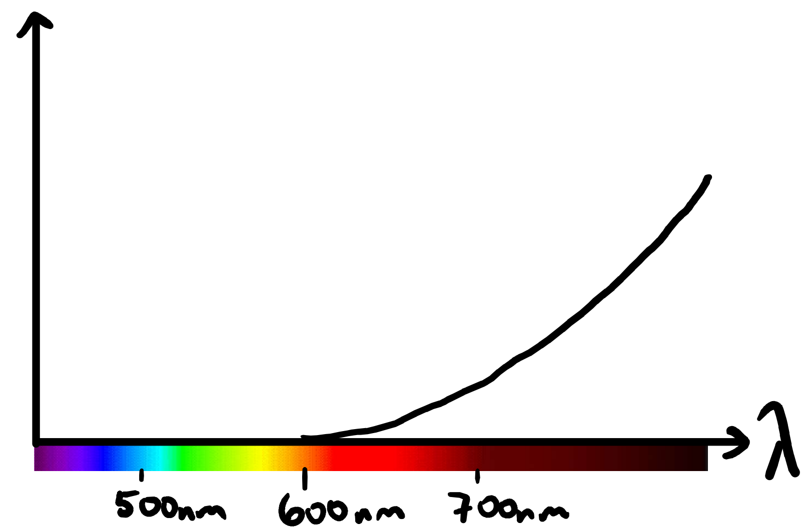
A)



B)



C)



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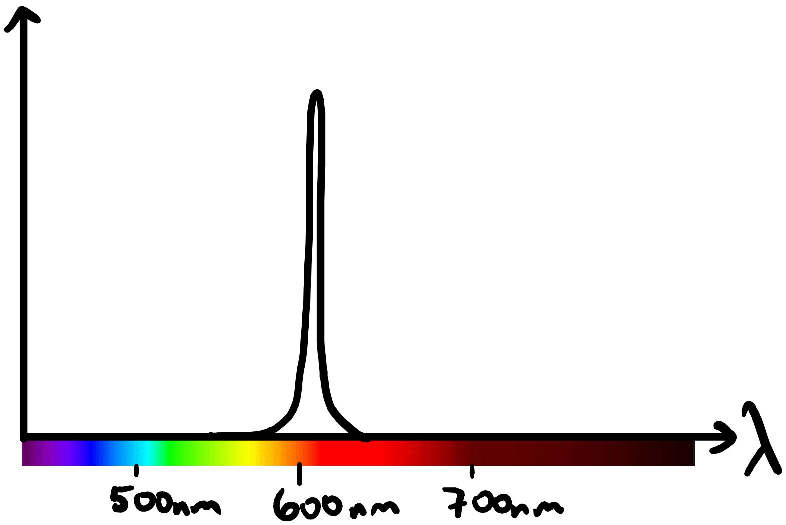
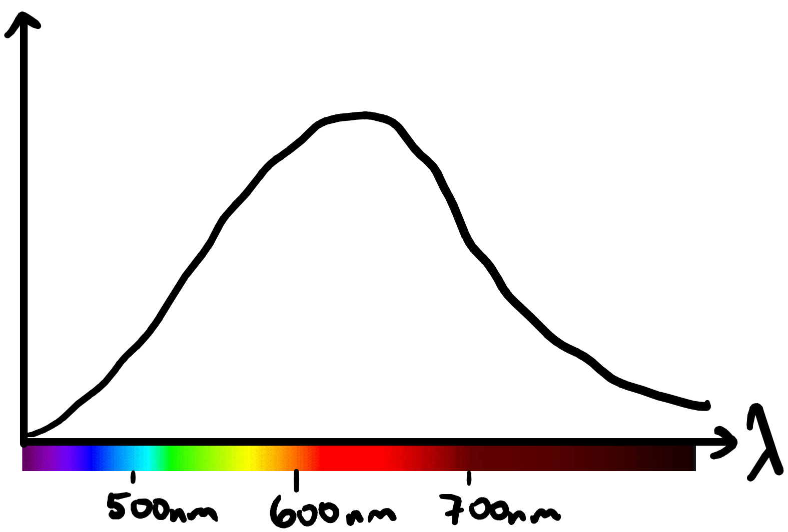
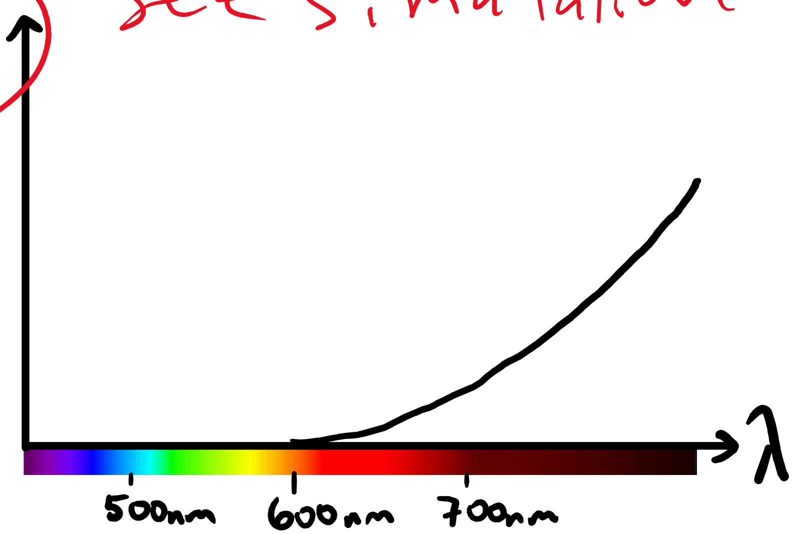


B)



C)

see simulation

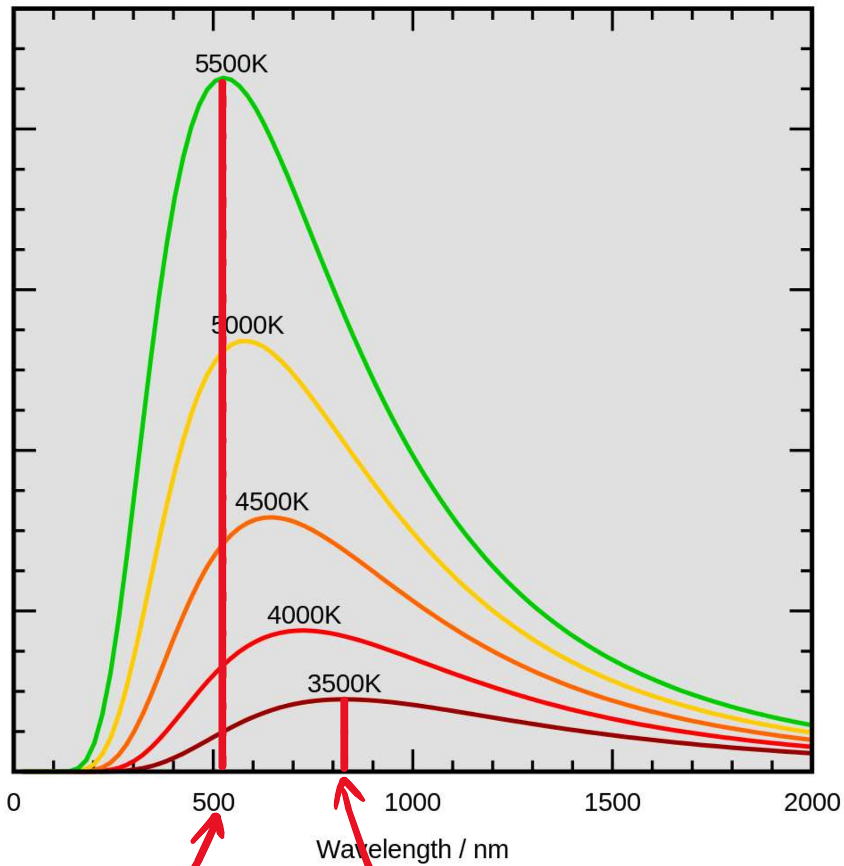


Blackbody spectrum

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

In the simulation, what properties of the thermal spectrum change as we change the temperature?

Peak wavelength is inversely proportional to T



λ_{max} for 5500K

λ_{max} for 3500K

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

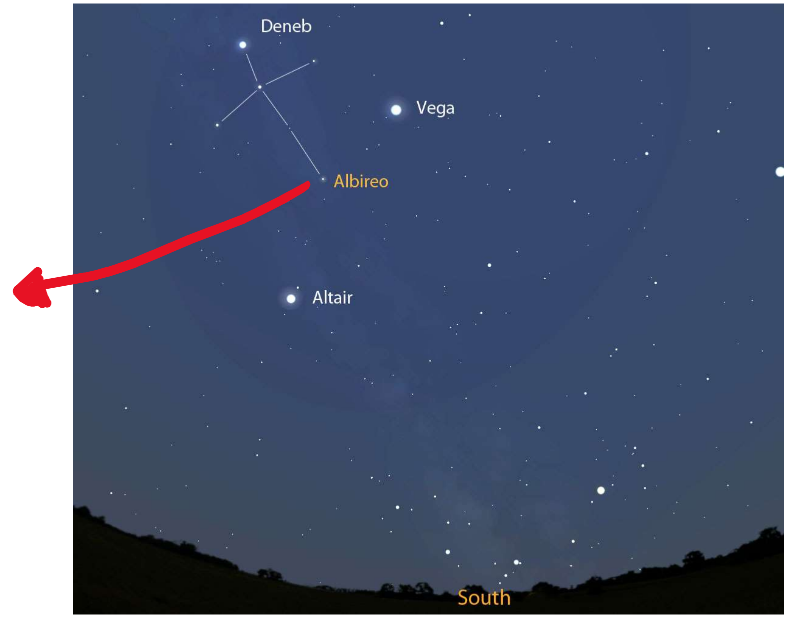
b: 2.9 K·mm

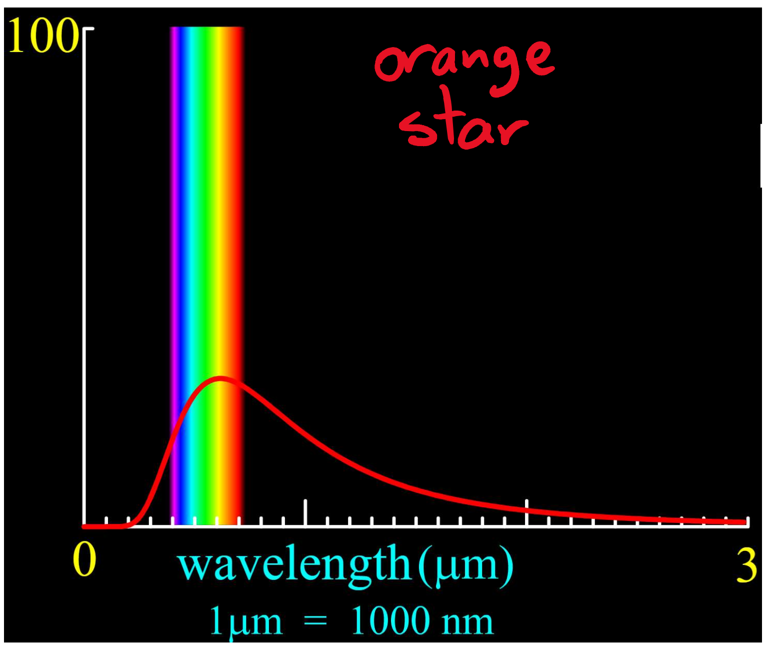
Wien displacement law

sun: peak at ≈ 500nm
→ 5700K

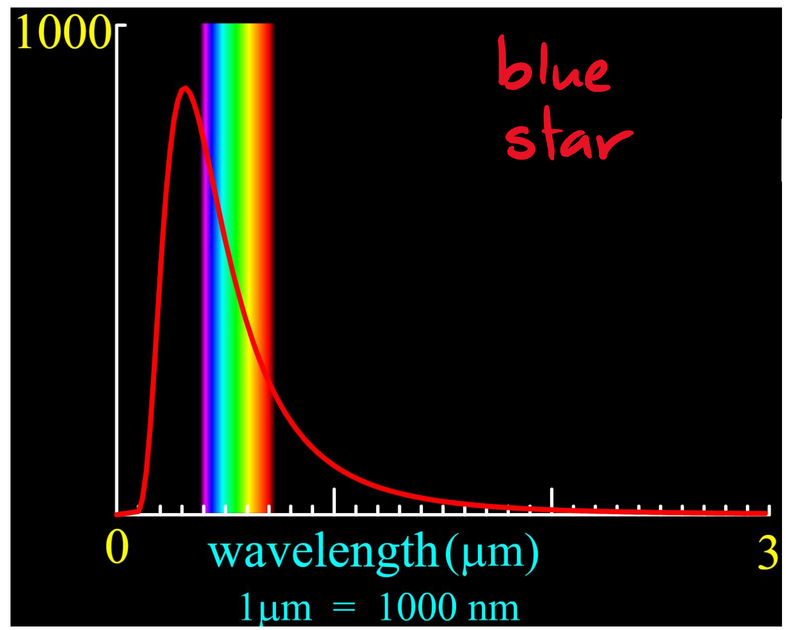
outer space: peak at 1mm
→ 2.7 K

"COSMIC MICROWAVE BACKGROUND"





$T \approx 4500K$

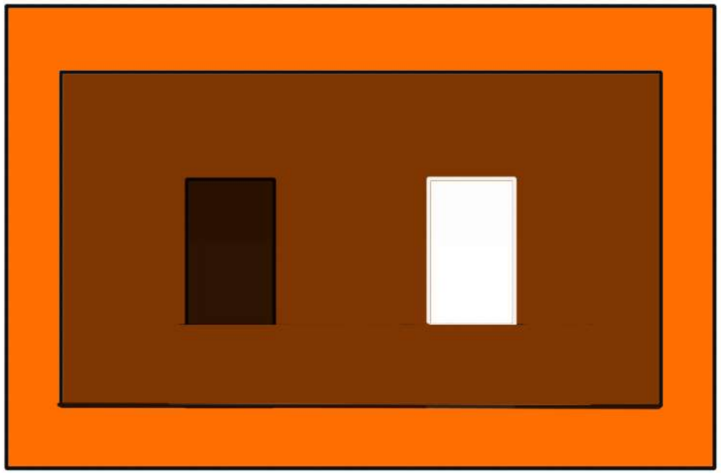


$T \approx 12{,}000K$

Total power is proportional to T^4

$$H = A \cdot e \cdot \sigma \cdot T^4$$

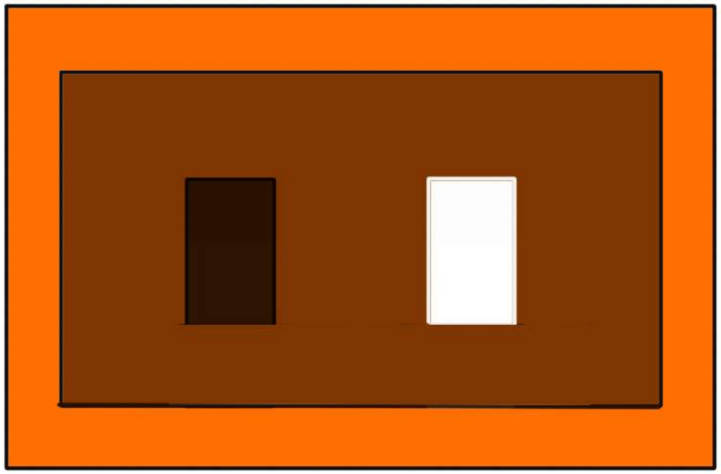
- H: heat current
- A: surface area
- e: emissivity
- σ: Stefan-Boltzmann constant, $5.67 \times 10^{8} \frac{W}{m^2 \cdot K^4}$



A white object and a black object both sit in an oven. The oven and the objects are in equilibrium at 1500 degrees Celcius. We can say that the **net** heat current from radiation, ($H_{absorbed}$ - $H_{emitted}$) 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.

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



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Equilibrium ⇒ const. T
⇒ no net heat current

∴ $H_{absorbed} - H_{emitted} = 0$

A) Larger for the white object
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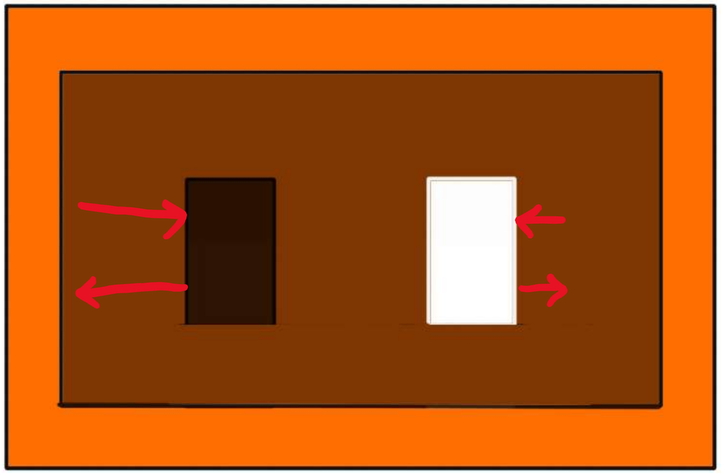
Assume that there is no air in the oven and the objects are insulated from the walls so there is no conduction or convection.



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$$H_{emitted} = H_{absorbed}$$

larger for black object

∴ black object radiates more!

EMISSIVITY:

- Perfect absorber = "blackbody"
  emits the most thermal radiation for a given temperature.

- Other objects: define

$$e = \frac{H}{H_{blackbody}}$$

→ depends on temperature

$e = 1$ blackbody

$e = 0$ perfect mirror

Total Power From Thermal Radiation

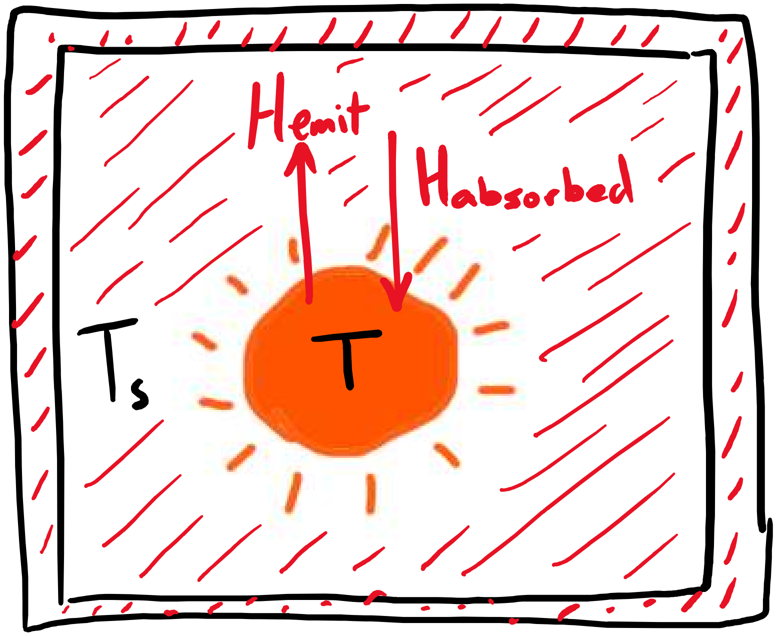
$$H = A \cdot e \cdot \sigma \cdot T^4$$

- H: heat current
- A: surface area
- e: emissivity
- σ: Stefan-Boltzmann constant, $5.67 \times 10^{8} \frac{W}{m^2 \cdot K^4}$

$e = 1$ perfect absorber (black)

$e = 0$ perfect reflector (mirror)

NET HEAT CURRENT FROM THERMAL RADIATION
(in uniform temperature environment)



surface area

$$H = A \cdot e \cdot \sigma \cdot (T^4 - T_s^4)$$

Stefan-Boltzmann constant

$5.67 \times 10^{8} \ \frac{W}{m^2 \cdot K^4}$

temp. of surroundings

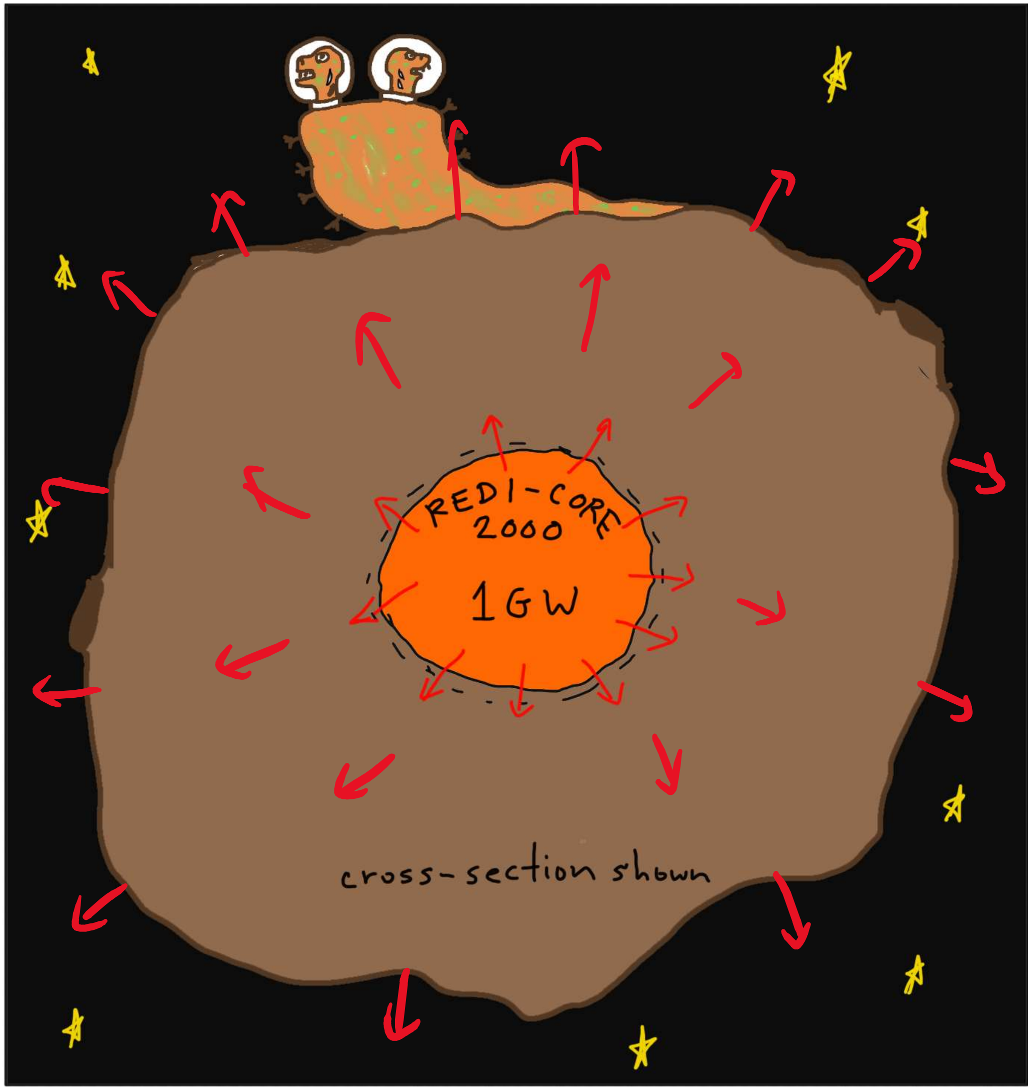
$e = 1$ perfect absorber (black)

$e = 0$ perfect reflector (mirror)

Yoltar heats their little planet (far from any stars) with a 1GW heater. If they wish to double the equilibrium *surface* temperature of their planet, they should increase the power of their heater to

A) 1.21GW
B) 2GW
C) 4GW
D) 8GW
E) 16GW

Hint: where does the energy from the heater go?



Steady state:

Power from heater = power radiated

$$P_{heater} = A \cdot \sigma \cdot e \cdot T^4$$

To double T

Need 16x P

A harder (but really interesting!) problem.

A planet with radius r = 6400km lies at a distance R = 150,000,000km from a yellow star with temperature T = 5700K and radius R_S = 695,000km. **Estimate the surface temperature of the planet.**

The planet has **albedo** (fraction of incident light reflected) A = 0.37 and emissivity *e* close to 1.

NEXT TIME