Phy100: Heat transport

Three basic forms of thermal heat transport

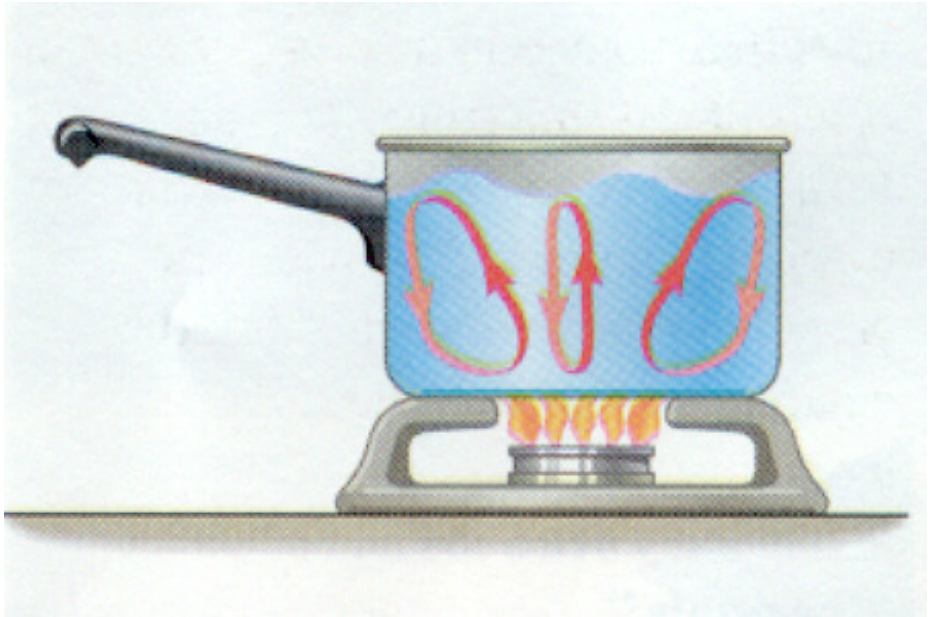
1) Conduction;

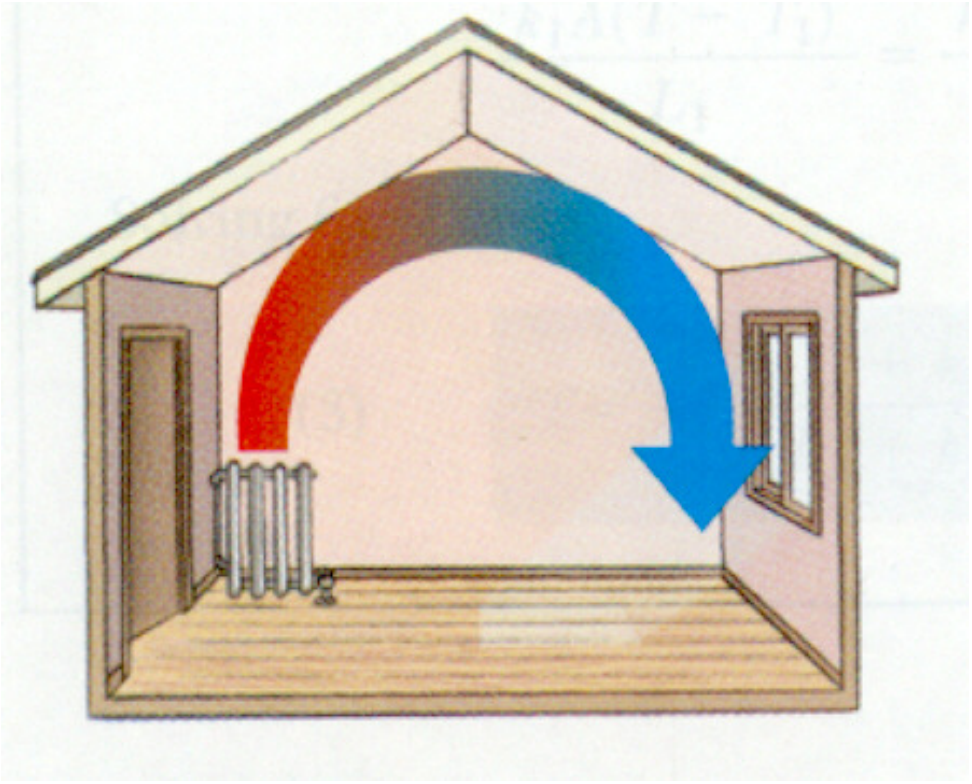
2) Convection;

3) Radiation.

Convection

Convection is heat transfer by motions of materials in a substance. Usually this occurs in a fluid (air or water) when fluids are moving from heat sources and carrying energy with it.





Radiation

Heat can also be transferred by radiating light (i.e. photons) or electromagnetic waves with different wavelengths.

In empty space, collisions or mass motions are impossible

and there are no conduction or convection and therefore radiation is the only mean to transfer heat. The heat is transferred from the sun to the earth mostly by visible light.

Radiation power spectrum

For a hot object with temperature T,

Q1: what kinds of photons are emitted (visible or invisible) ?
Q2: How much energy emitted per second, i.e. radiation power?

About electromagnetic waves:

1) Radiation as a self-propagating electric and magnetic (EM) wave.

2) Any form of radiation or EM waves moves at the speed of light
c=3 X 10^8 m/s or 300,000km/s (Boeing Jet cruise speed about 0.3km/s)

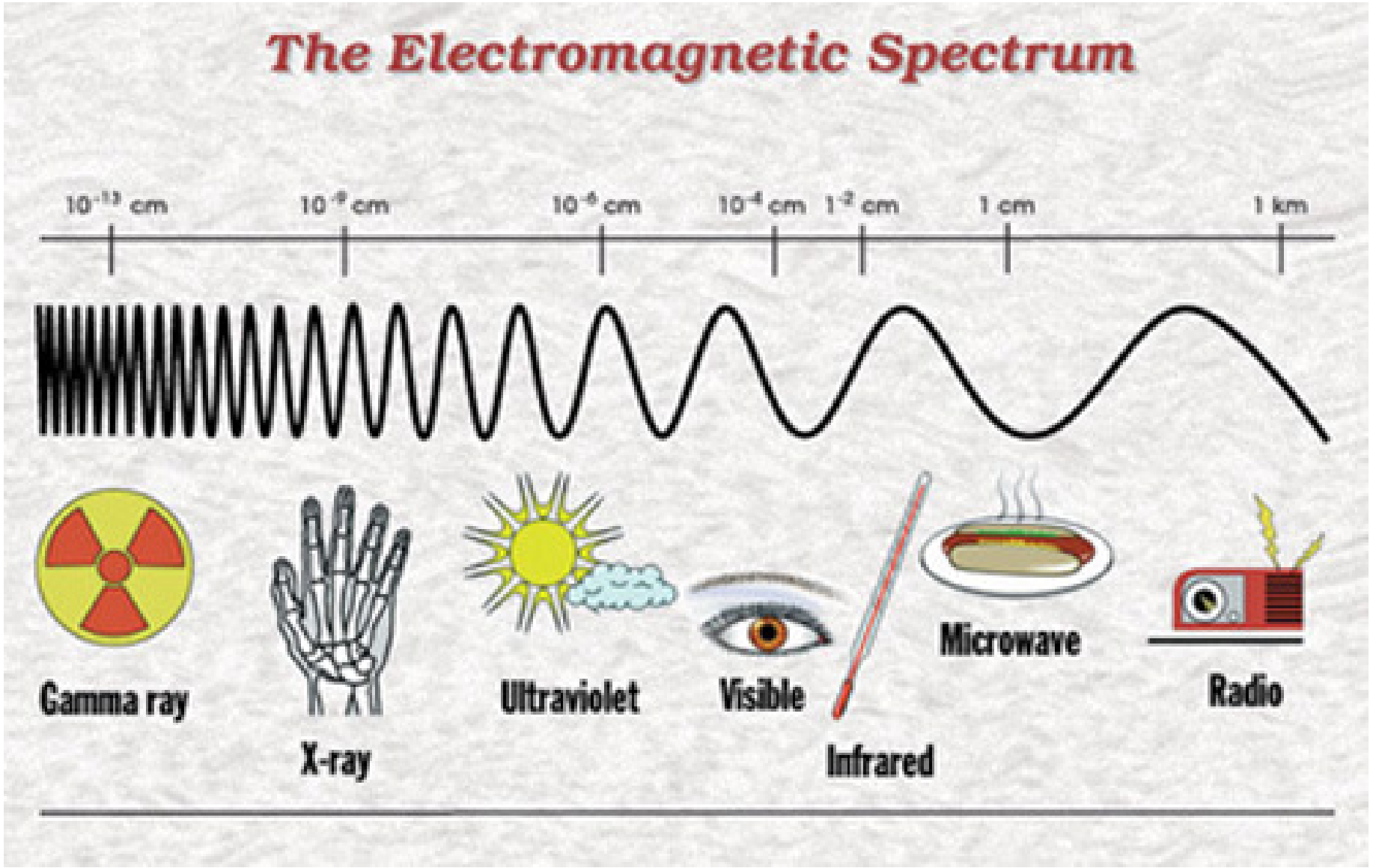
3) In electromagnetic waves, both electric fields and magnetic fields Oscillate as a function of time and spatial coordinates. These waves consist are crests and troughs.

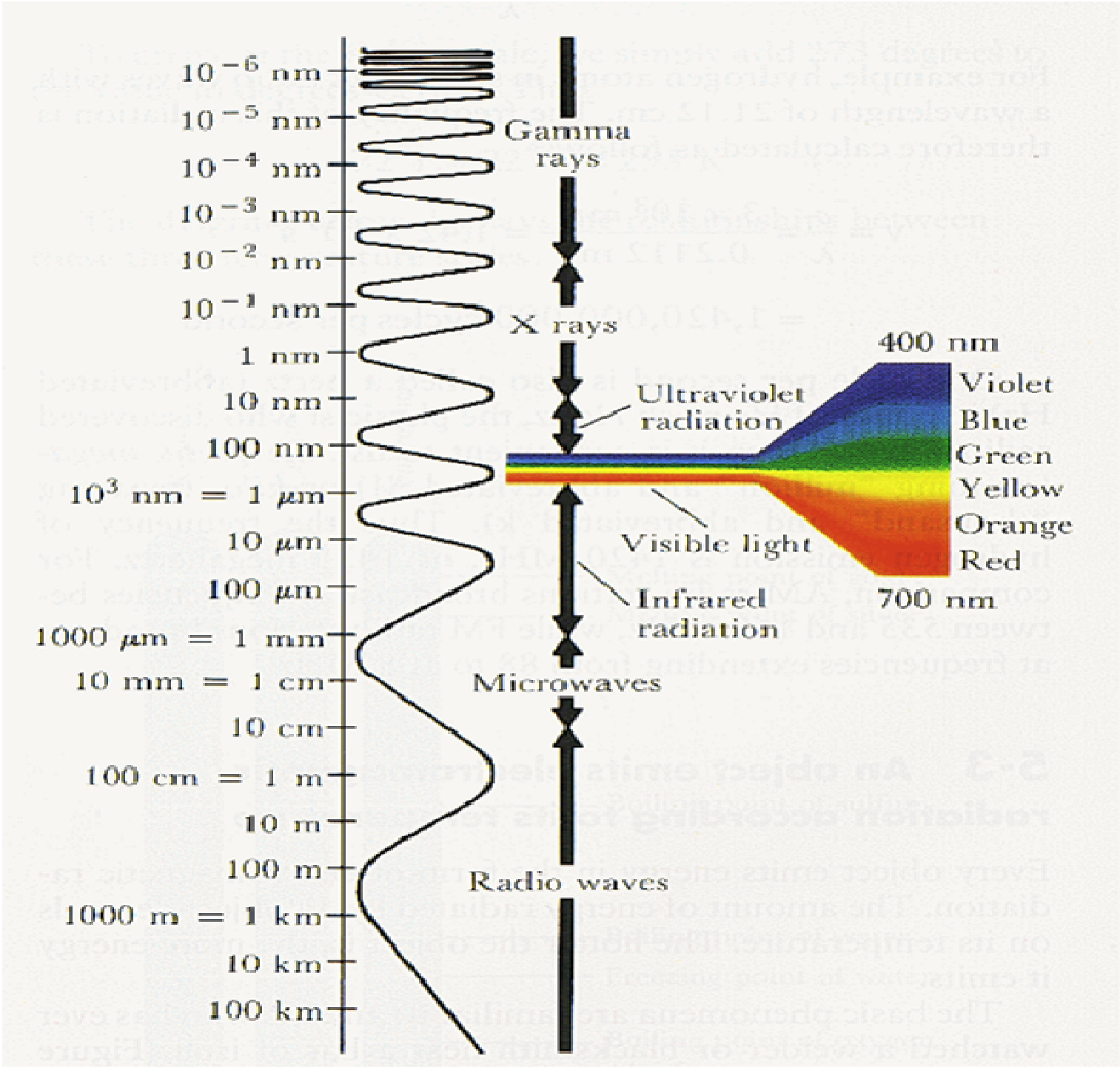
The distance between two adjacent crests = wavelength.

The number of crests one observes at a given point in one second =Frequency

wavelength X frequency = speed of light

Full range of forms of radiation

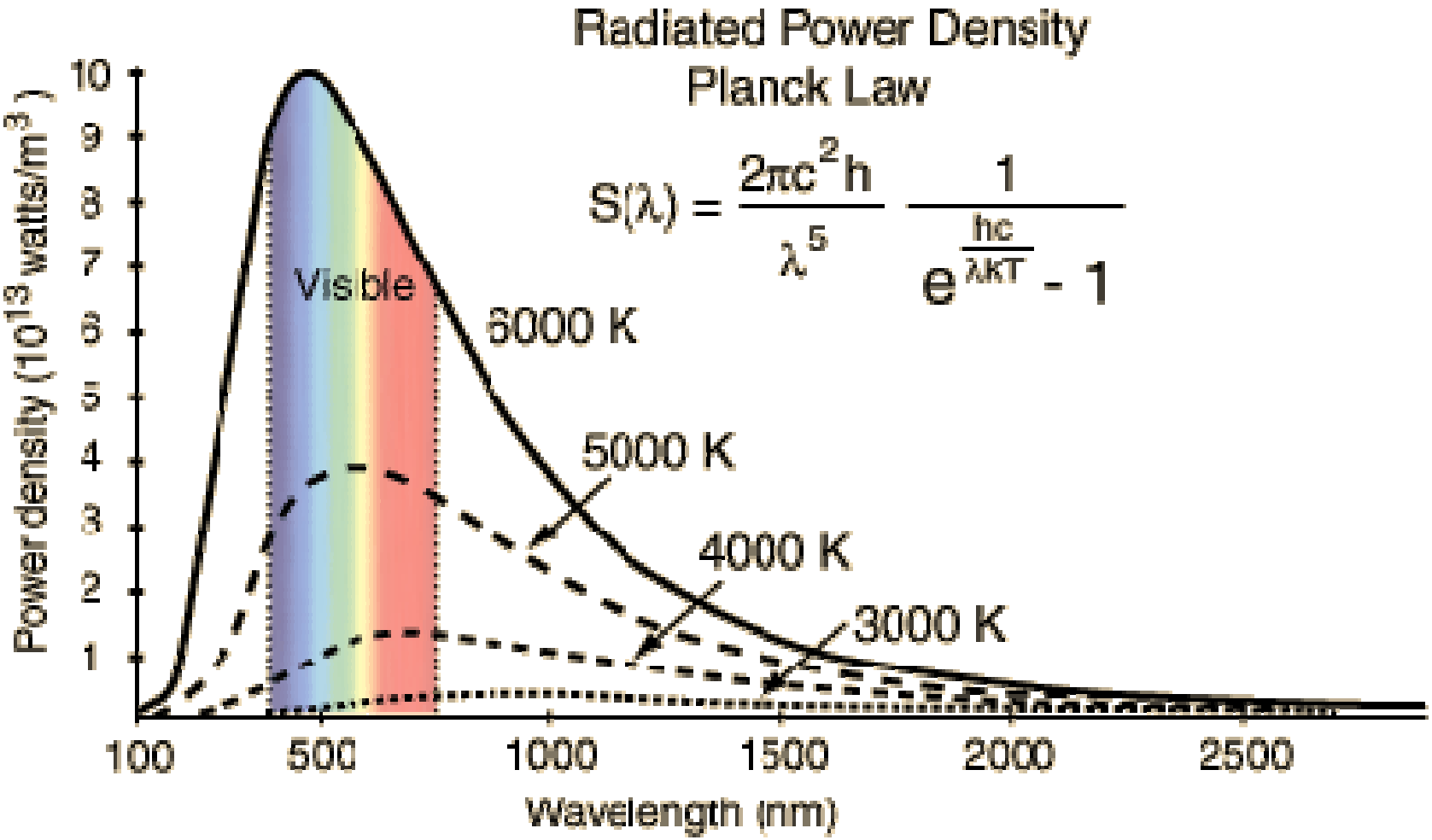



10^{-5} nm
10^{-4} nm
10^{-3} nm
10^{-2} nm
10^{-1} nm
1 nm
10 nm
100 nm
10^3 nm = 1 μm
10 μm
100 μm
1000 μm = 1 mm
10 mm = 1 cm
10 cm
100 cm = 1 m
10 m
100 m
1000 m = 1 km
10 km
100 km
Gamma rays
X rays
Ultraviolet radiation
Visible light
Infrared radiation
Microwaves
Radio waves
400 nm
Violet
Blue
Green
Yellow
Orange
Red
700 nm

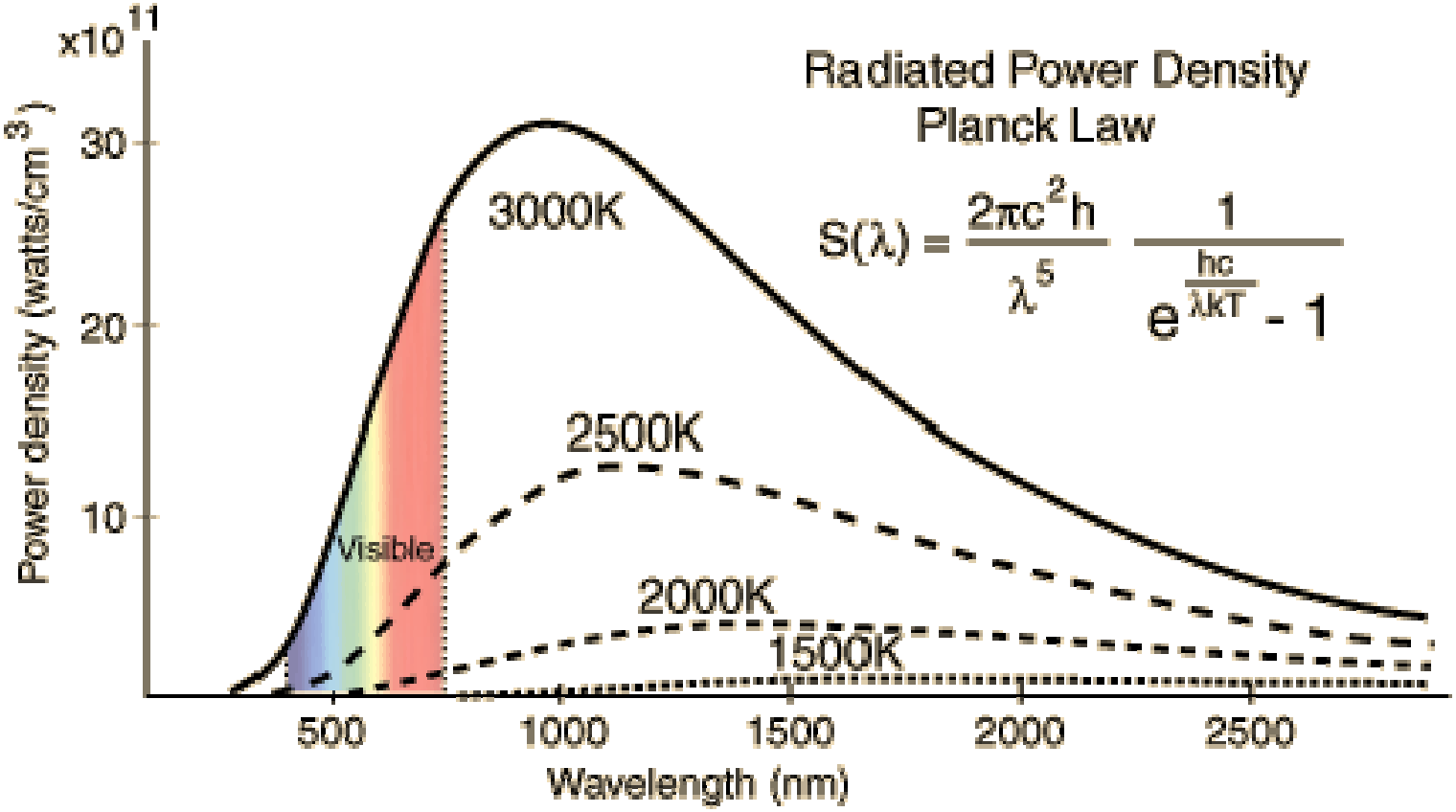
Blackbody radiation

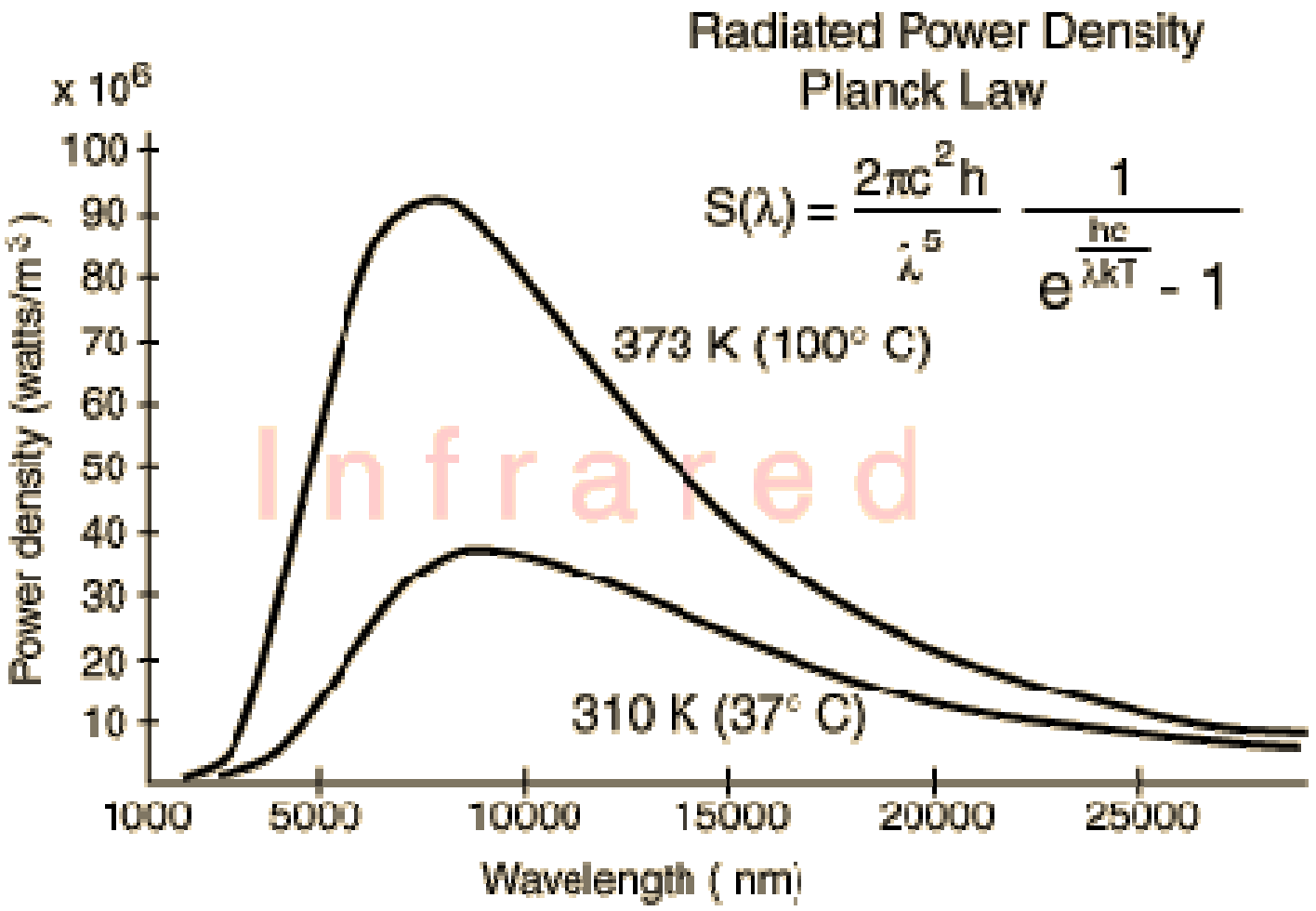
$$\Delta P = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \Delta\lambda A$$

Radiation power
in a given wave length interval delta-lamba at wavelength lambda

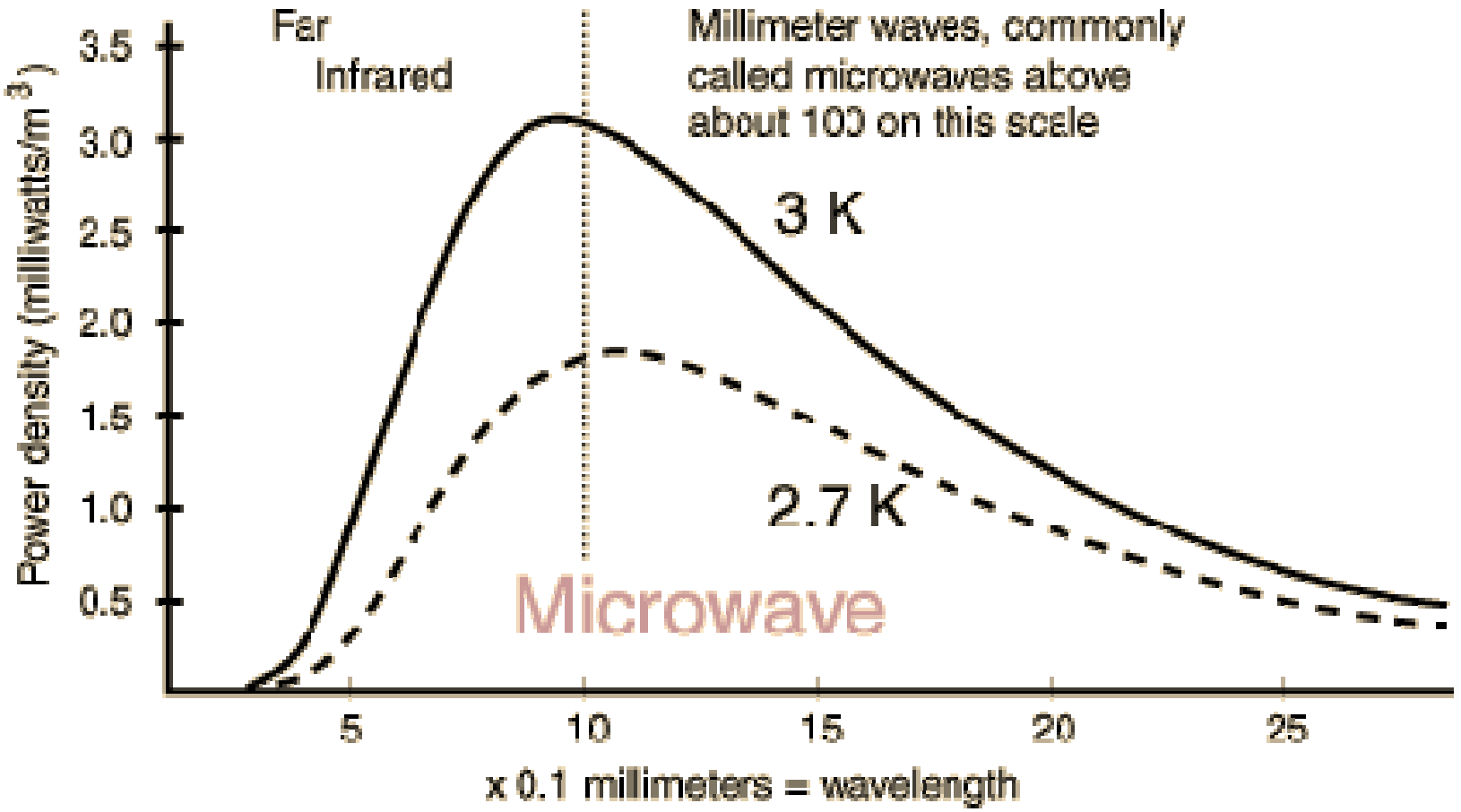


Blackbody radiation at T=3000K-6000K


x10^11
Power density (watts/cm^3)
30
20
10
3000K
2500K
2000K
1500K
Visible
500
1000
1500
2000
2500
Wavelength (nm)
Radiated Power Density
Planck Law
S(λ) = 2πc^2h / λ^5 · 1 / (e^(hc/λkT) - 1)



Blackbody radiation at T=310K



Blackbody radiation at T=3K

Conclusions

1) **Radiation power concentrated in an interval of wavelength.**
   The peak position in the power spectrum move to longer wavelengths when T decreases;

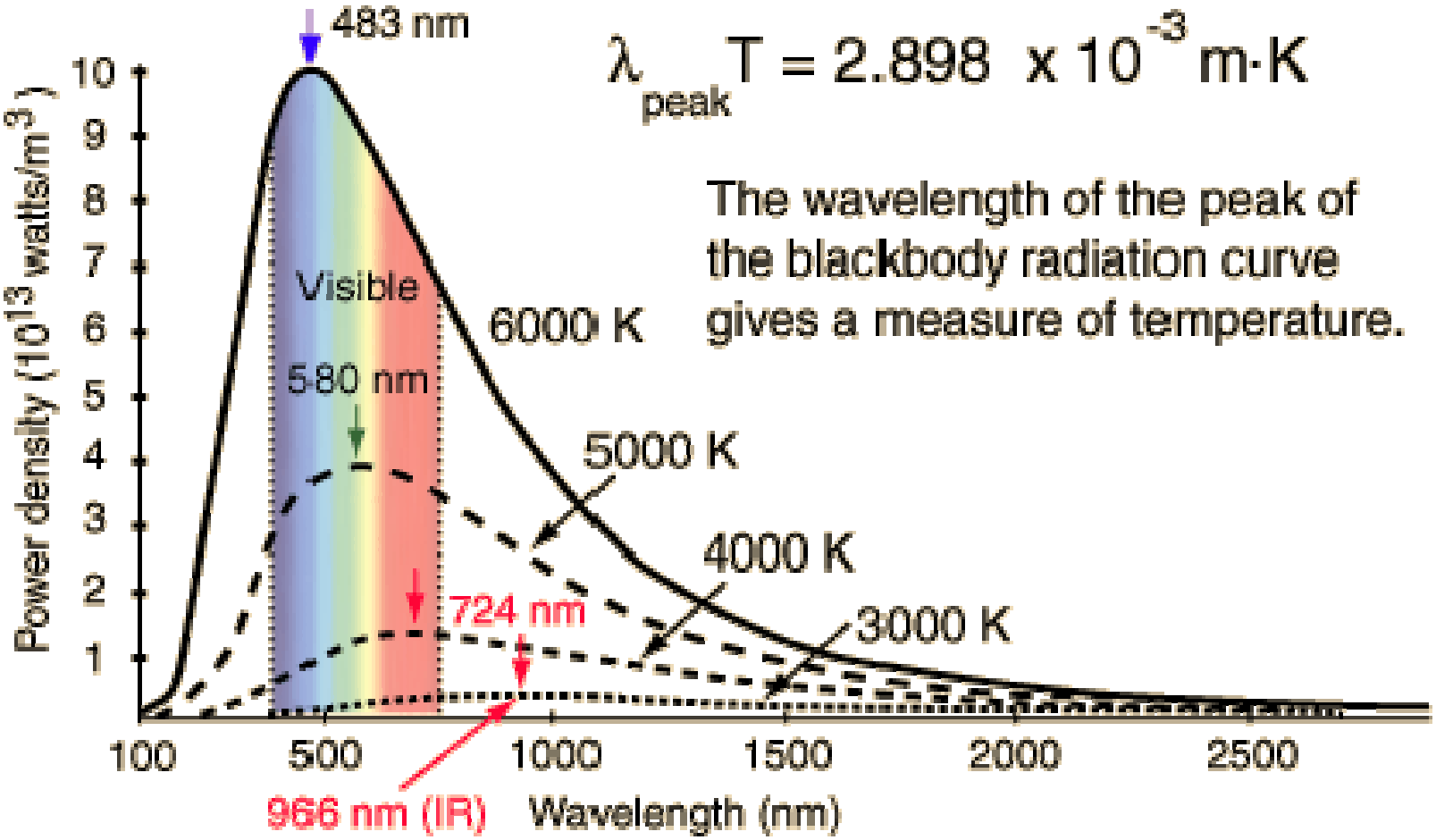
2) **The integrated radiation power (the area below the power spectrum) decreases as T decreaes.**

$$\lambda_{peak} T = 2.898 \times 10^{-3} \, m \cdot K$$

Wien's displacement law

$$\frac{P}{A} = \sigma T^4 \; j/m^2 s$$ Stefan-Boltzmann Law

$$\sigma = 5.6703 \times 10^{-8} \; watt / m^2 K^4$$


483 nm
$\lambda_{peak} T = 2.898 \times 10^{-3}$ m·K
The wavelength of the peak of the blackbody radiation curve gives a measure of temperature.
Power density (10^{13} watts/m^3)
10
9
8
7
6
5
4
3
2
1
Visible
580 nm
6000 K
5000 K
4000 K
3000 K
724 nm
966 nm (IR)
100
500
1000
1500
2000
2500
Wavelength (nm)