Chapter 3: Radiation and Energy Balance

Feb 4 & 9

3.1. Temperature and Energy
3.2. Electromagnetic Radiation
3.3. Blackbody Radiation
3.4. Energy Balance
Terms
Problems

Revisit the lecture notes on Jan 14, 2026

- Unit
- Energy
- Wavelength
- Cosine Law

3.1. Temperature & Energy

Energy: capacity to do work (W, J/s, W/m^2)

Internal Energy: refers to how fast atoms and molecules in object are moving.

- For solids, atoms approximately fixed in space.
- For fluids, molecules can move (e.g., water, air).

Temperature: measure of internal energy of an object (K, ^oF, ^oC)

- As molecules of object speed up, internal energy increases, and temperature increases (e.g., add pressure).

3.2. Electromagnetic Radiation

Most (all) warmth of our climate provided by Sun.

Sun positioned ~150 mil km from Earth, with vacuum of space in between.

How does energy from Sun reach Earth?

- Energy transported by electromagnetic radiation.
- **Electromagnetic Radiation:** gamma, X-rays, ultraviolet, visible, infrared, microwave, radio waves.
- The wavelength is the distance between two wave peaks.
  - ✓ Long wavelength → low energy
  - ✓ Short wavelength → high energy

3.2. Electromagnetic Radiation

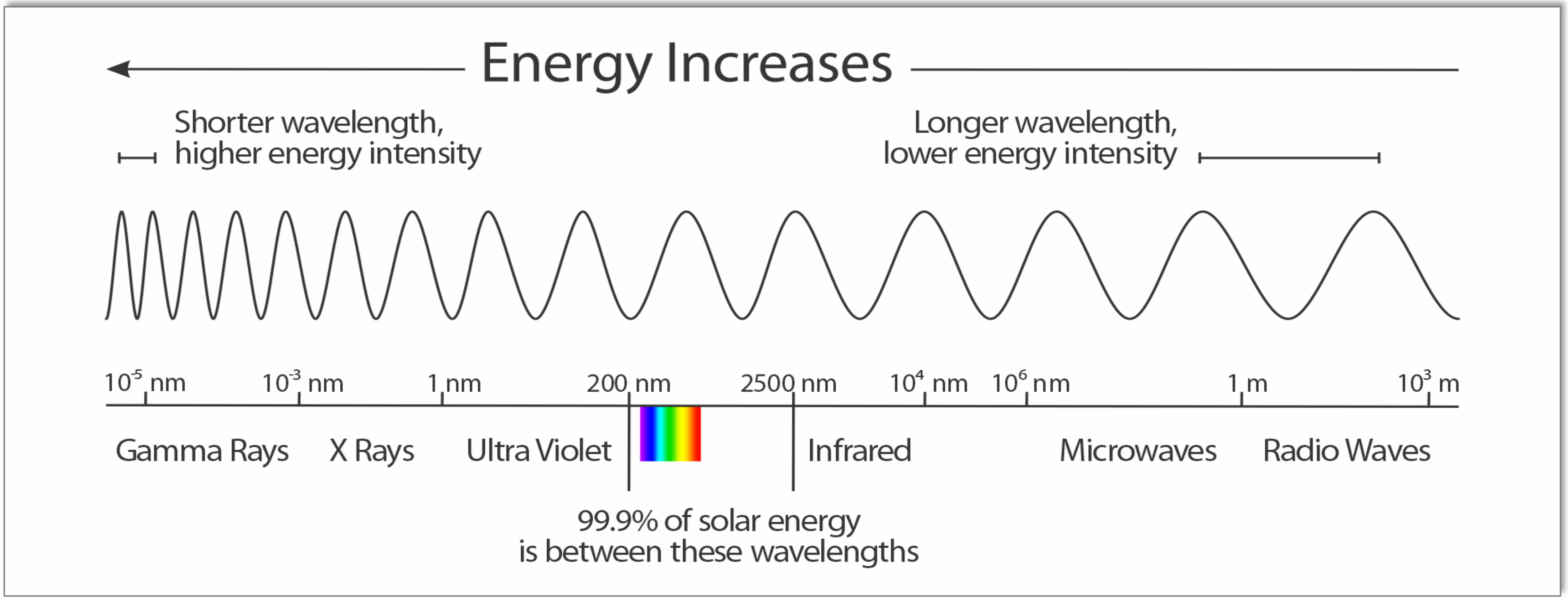
Ripples spreading across a pond, except the ripples are electric and magnetic fields instead of water.

Electromagnetic radiation as stream of photons:

- Photons: small discrete packages of energy.
- As photons travel from Point A to Point B, each one carries small amount of energy.
- Photons have characteristic size, referred to as:
  - ✓ Wavelength = determines how photons interact with world (λ, lambda).
  - ✓ Micron (micrometer, **µm**) = 1 millionth of a meter.
  - ✓ Nanometer (**nm**) is also used (1 nm = 10^{-9} meters)
  - ✓ 1 µm = 1000 nm

3.2. Electromagnetic Radiation

Wavelength



https://www.rmets.org/news/wmo-provisional-report-state-global-climate-2021

3.2. Electromagnetic Radiation

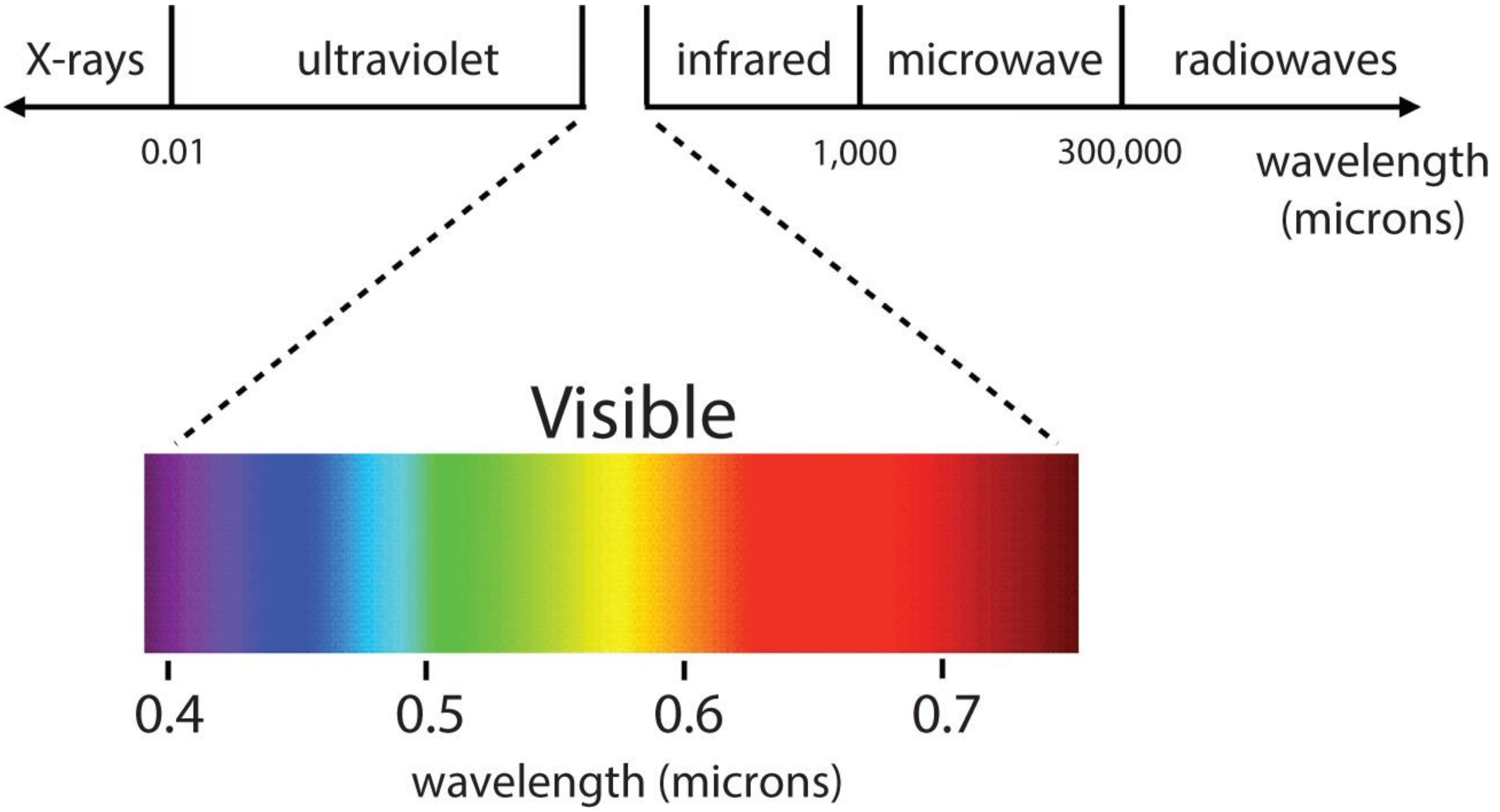


Fig. 3.1: Electromagnetic spectrum. Note that visible part makes up only minor part of spectrum.

A few facts:

Speed of light (c): c = 299,792,458 m/s

$\approx 3.0\times10^{8}$ m/s

≈ 300,000 km/s

≈ 186,282 miles/s

- Light takes about **8 min and 20 s** to travel from the Sun to Earth.
- Light can circle Earth **7.5 times** per second.
- It takes about **1.3 s** for light to travel from the Moon to Earth with a distance of 384,400 km (238,855 miles).
- It takes about **3–22 min** to travel between Earth and Mars

3.2. Electromagnetic Radiation

Wavelength determines photon physical properties:

- Visible and infrared photons can not go through walls, but radio waves can.
- Human eye can detect visible photons but not others.
- At airport security, machine uses microwaves, which can go through clothing, but stopped by denser materials, such as flesh or weapons.
- Atmosphere largely transparent to visible photons, but less so to infrared.

3.2. Electromagnetic Radiation

Sun and lamp both emit photons – *we can see emitted visible light*.

However, everything emits photons, all of the time!

- If true, why do you not glow like a lightbulb?
- **Answer**: wavelength emitted determined by object temperature.

Emission spectrum: shows power carried away from object by photons at each wavelength.

3.3. Blackbody Radiation

Blackbody
Any object with a temperature higher than absolute zero (-273.15 °C) emits energy.

Stefan–Boltzmann Law

The total energy (E) radiated from an object is proportional to the 4th power of its temperature (T), with σ as the emissivity (i.e., Stefan–Boltzmann constant):

$$E = \sigma \cdot T^4$$

$\sigma = 5.67 \times 10^{-8}\,\mathrm{W} \cdot \mathrm{m}^{-2} \cdot \mathrm{K}^{-4}$

Grey Body: actual emissivity (ε)

$$E = \varepsilon \cdot \sigma \cdot T^4$$

- A perfect blackbody: $\varepsilon = 1$
- Real materials: $0 < \varepsilon < 1$

3.3. Blackbody Radiation

Planck’s Radiation Law

The electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature is described by :

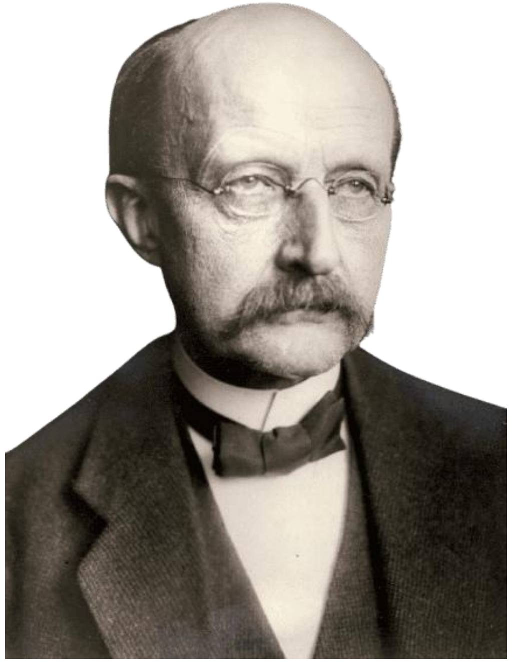
$$E = \frac{h \cdot c}{\lambda}$$

h = Planck’s constant; 6.62607015×10^{-34} joule/s (J/s)

λ = frequency of radiation (nm)

c = speed of light (m/s)

Planck’s Law is a mathematical relationship formulated in 1900 by German physicist Max Planck to explain the spectral-energy distribution of radiation emitted by a blackbody (a hypothetical body that completely absorbs all radiant energy falling upon it, reaches some equilibrium temperature, and then reemits that energy as quickly as it absorbs it).



3.3. Blackbody Radiation

Wien's Law

as temperature of some blackbody object increases, wavelength of peak of emission spectrum decreases!

$$\lambda_{max} = \frac{2897}{T} \qquad (3.1)$$

where,

- T is temperature of blackbody (K)
- λ_{max} is wavelength of peak of emission spectrum (µm).

Question:

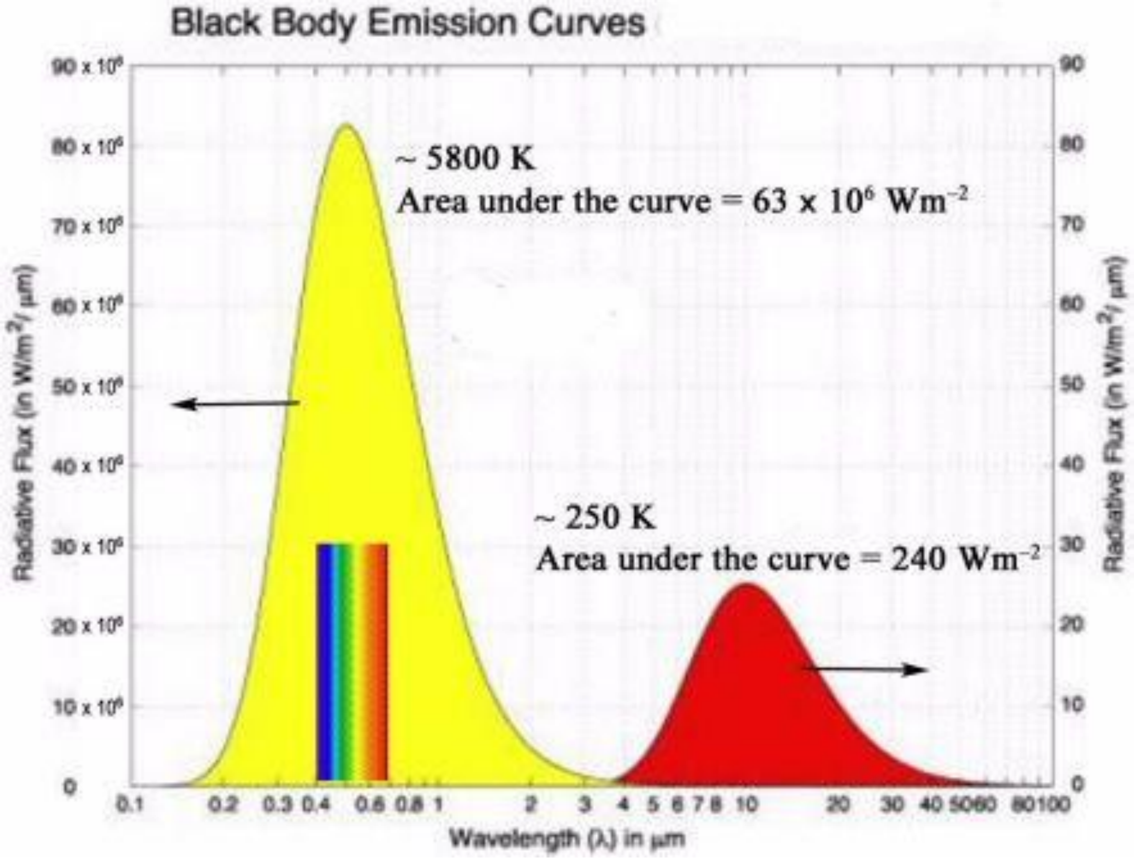
What is the peak wavelength of human body?

Answer:

3.3. Blackbody Radiation

1) Radiant emittance from the sun (T = 6000 K) varies from 0.2 nm to 3.0 nm and peaks at spectra of ~0.55 nm, with most energy coming from a wavelength of 0.3-0.7 nm (>50%). These wavelengths are loosely called “shortwave radiation” or “visible light”).

2) The Earth’s (T = 288 K) peak emittance is 9.5-10.0 nm. In sum, Earth’s temperature is mostly maintained by the balance of incoming shortwave radiation from the sun and outgoing longwave radiation from the Earth.



Distribution of energy (W/m^2/µm) emitted by the sun and the Earth by wavelength

3.3. Blackbody Radiation

Peaks

a) 300-K curve at ~10 µm

b) 1600-K curve at ~1.8 µm

c) 6000-K curve at ~0.5 µm

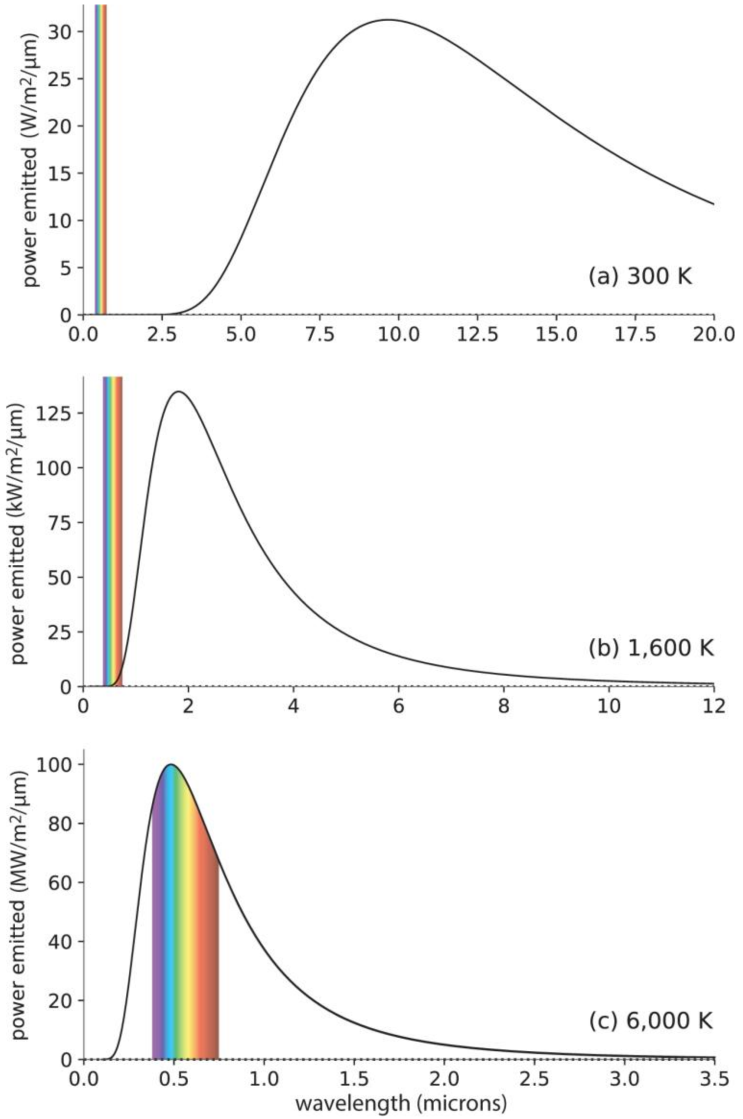


Fig. 3.2: Power emitted at different wavelengths from objects at three temperatures: (a) 300 K, (b) 1600 K, (c) 6000 K. Rainbow band on each plot shows range of wavelengths visible to human eye.

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Take-Home Messages

- Major physical laws on radiation energy
- Solar radiation and distribution
- Short- and Long-wave radiation (all waves)
- Amount of energy by wavelength