Radiation Heat Transfer

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Lecture 1 **Introduction**

Reference books

- Incropera, F. P., Dewitt, D. P., Bergman, T., & Lavine, A. (2002). Fundamentals of mass and heat transfer. *Australia: John Wiley and Sons*.
- Holman, J. P. (1986). Heat transfer, 1986. *Mc Gran–Hill Book Company, Soythern Methodist University*.
- Modest, M. F. (2013). Radiative heat transfer. Academic press.

Various Electromagnetic Radiations

$$c = \lambda \upsilon$$

$$E = h\upsilon$$

Planck's constant

$$h = 6.625 \times 10^{-34}\ \mathrm{J.}\,s$$

Using relativistic relation and quantum statistical thermodynamics

$$E_b = \sigma\, T^4$$

Stefan-Boltzmann's constant

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

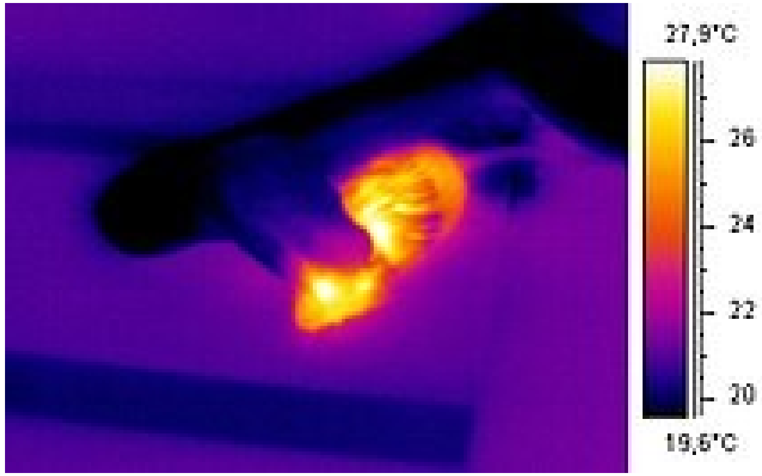
Microwave

Small microwave oven on a kitchen counter

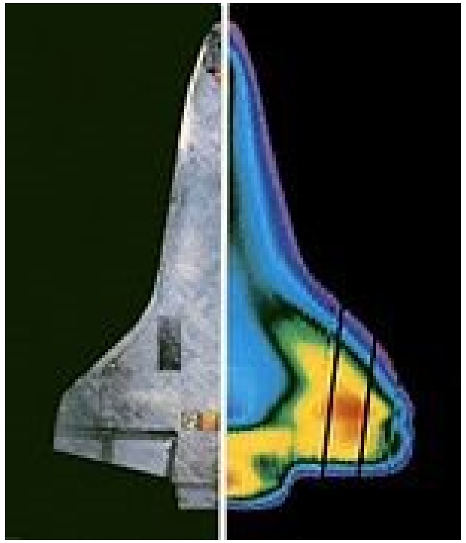
The parabolic antenna (lower curved surface) of an ASR-9 airport surveillance radar which radiates a narrow vertical fan-shaped beam of 2.7–2.9 GHz (S band) microwaves to locate aircraft in the airspace surrounding an airport

Some of the dish antennas of the Atacama Large Millimeter Array (ALMA) a radio telescope located in northern Chile. It receives microwaves in the millimeter wave range, 31 – 1000 GHz

Infrared radiation (IR)

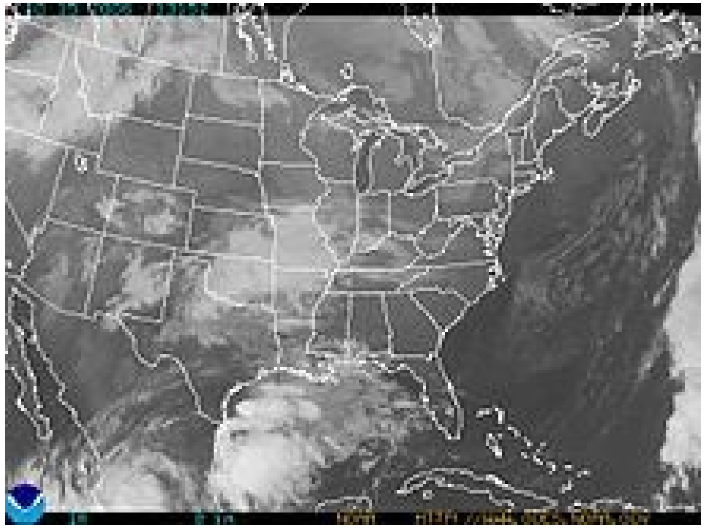


Thermographic image of a snake eating a mouse



Thermography helped to determine the temperature profile of the Space Shuttle thermal protection system during re-entry

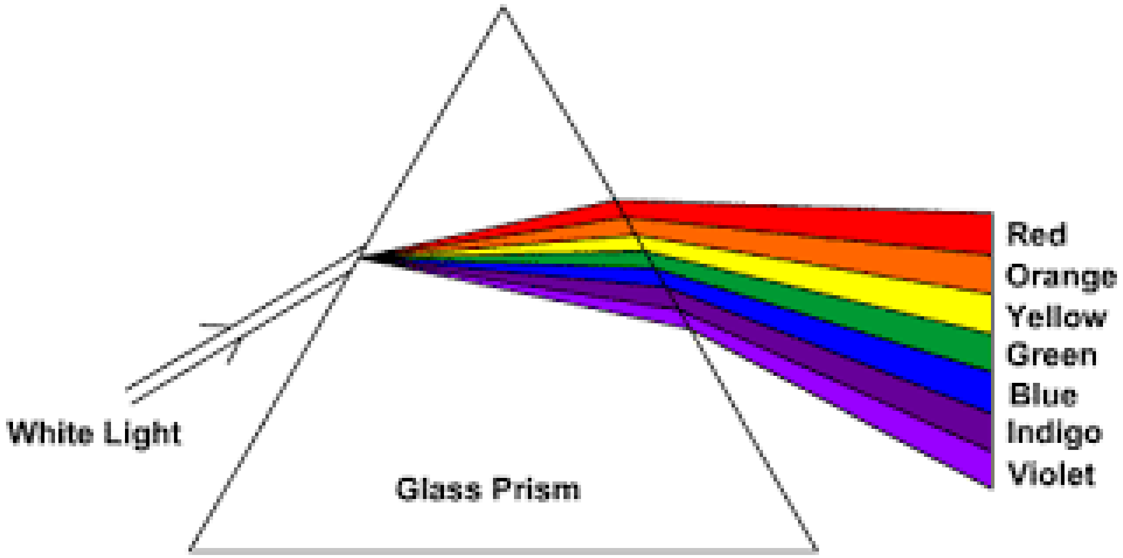
A comparison of a thermal image (top) and an ordinary photograph (bottom) shows that a trash bag is transparent but glass (the man's spectacles) is opaque in long-wavelength infrared.



R Satellite picture taken 1315 Z on 15th October 2006. A frontal system can be seen in the Gulf of Mexico with embedded Cumulonimbus cloud.

Visible spectrum

Color	Wavelength	Frequency	Photon energy
Violet	380–450 nm	668–789 THz	2.75–3.26 eV
Blue	450–495 nm	606–668 THz	2.50–2.75 eV
Green	495–570 nm	526–606 THz	2.17–2.50 eV
Yellow	570–590 nm	508–526 THz	2.10–2.17 eV
Orange	590–620 nm	484–508 THz	2.00–2.10 eV
Red	620–750 nm	400–484 THz	1.65–2.00 eV




Rainbow

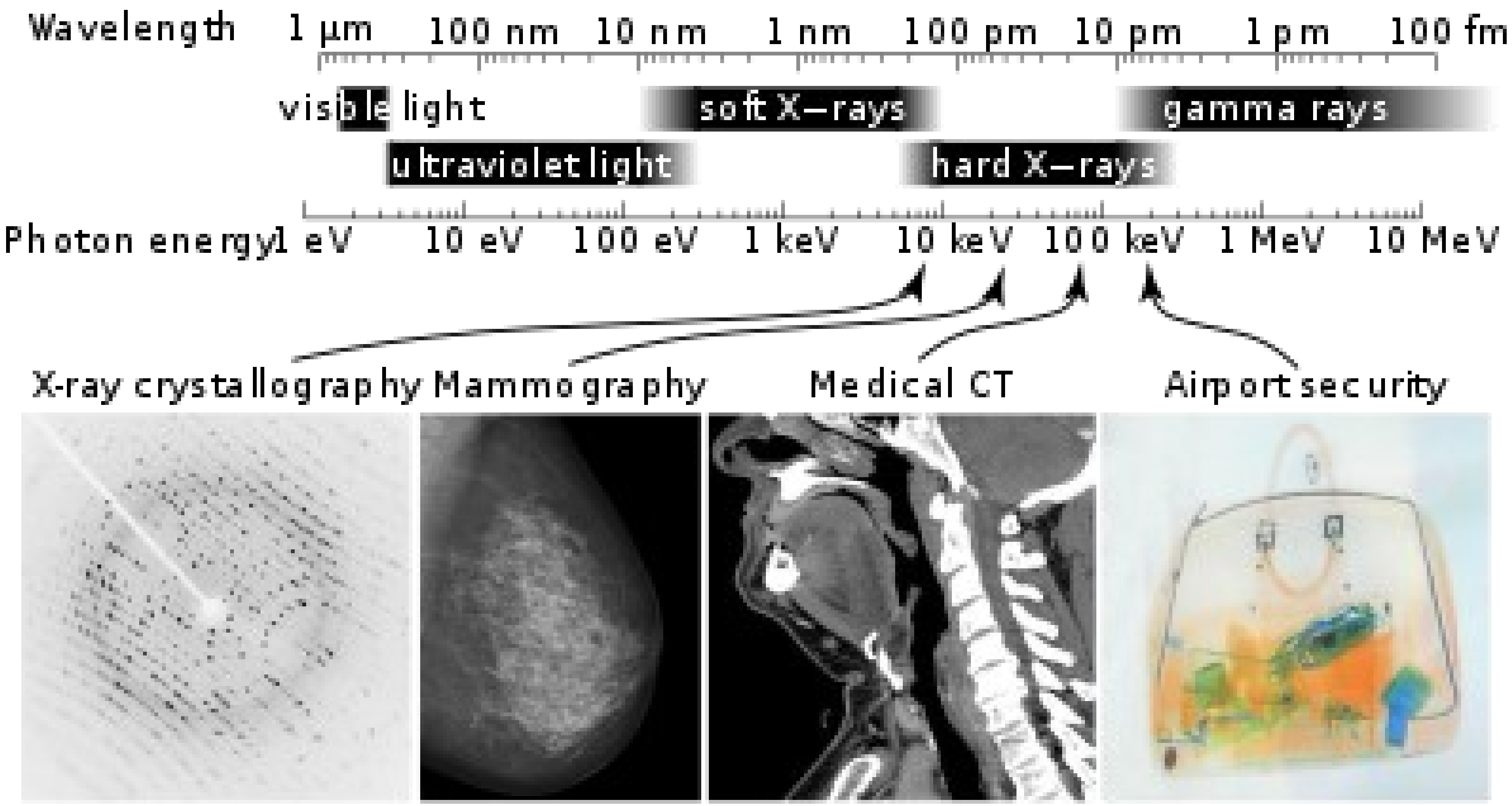
Ultraviolet (UV)

UV damaged polypropylene rope (left) and new rope (right)

9-watt germicidal UV lamp, in compact fluorescent (CF) form factor

UV radiation is also produced by electric arcs. Arc welders must wear eye protection and cover their skin to prevent photokeratitis and serious sunburn

X-Rays

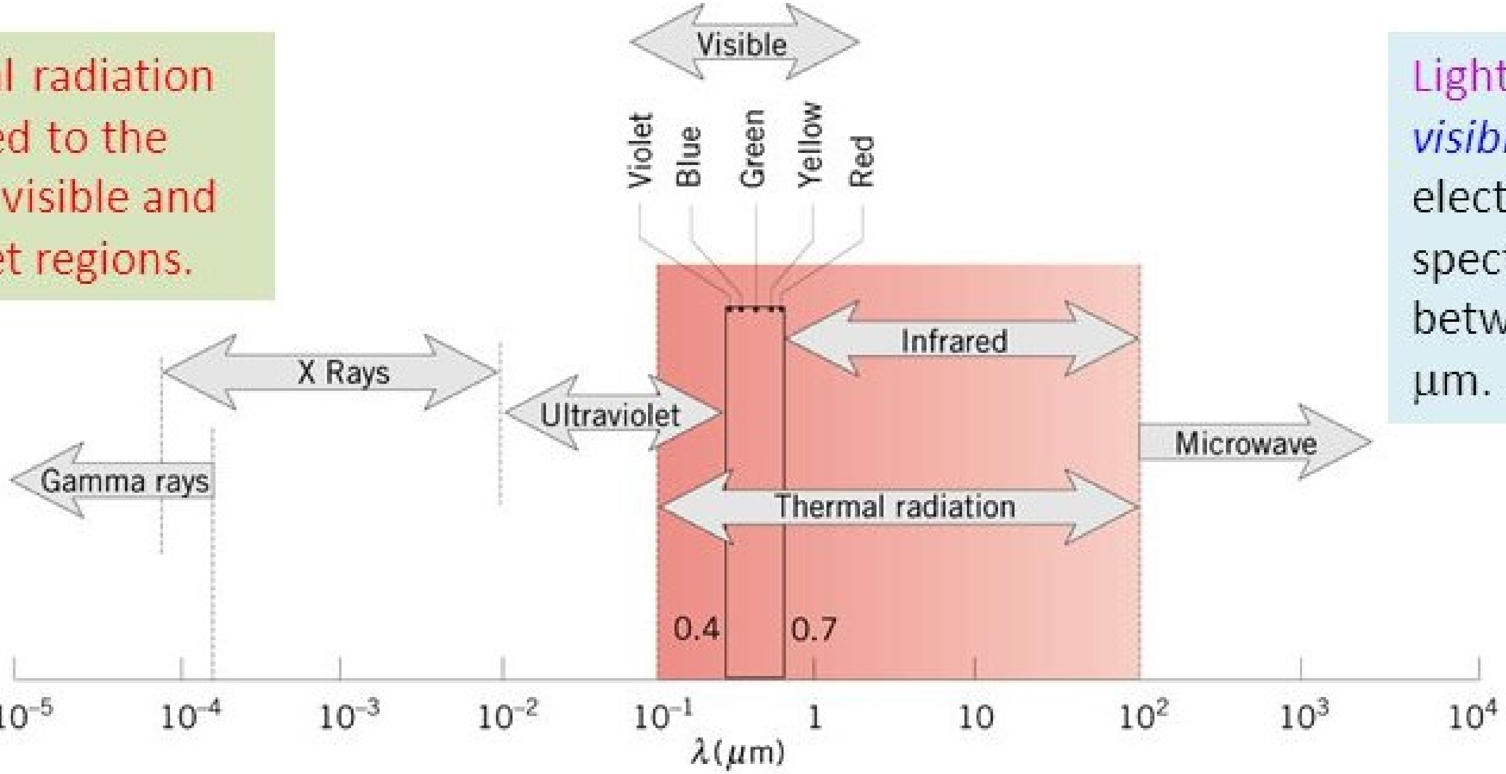

Wavelength
1 μm
100 nm
10 nm
1 nm
100 pm
10 pm
1 pm
100 fm
visible light
soft X-rays
gamma rays
ultraviolet light
hard X-rays
Photon energy
1 eV
10 eV
100 eV
1 keV
10 keV
100 keV
1 MeV
10 MeV
X-ray crystallography
Mammography
Medical CT
Airport security

γ-Rays

Gamma rays are emitted during nuclear fission in nuclear explosions

The Electromagnetic Spectrum

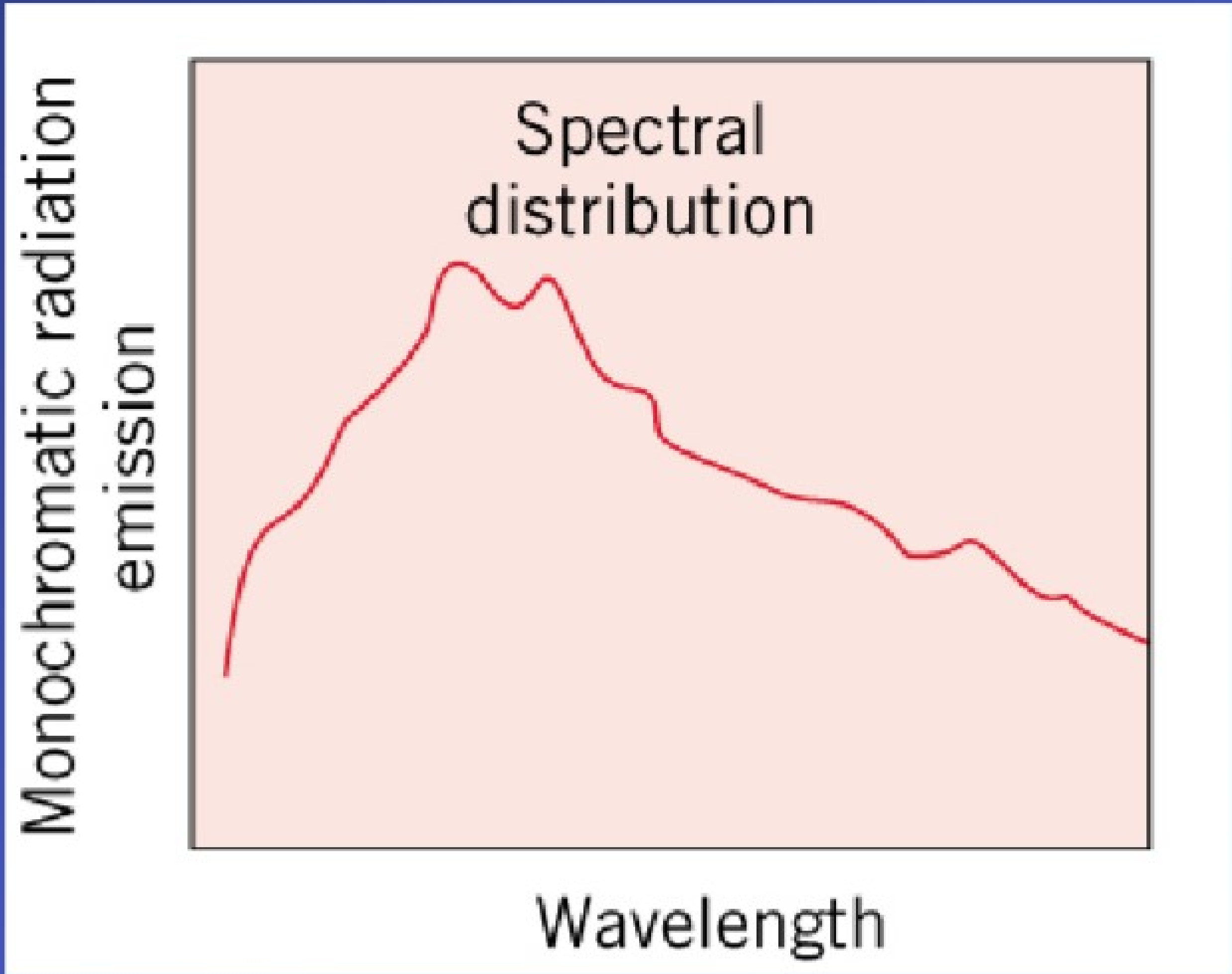
* Thermal radiation is confined to the infrared, visible and ultraviolet regions.



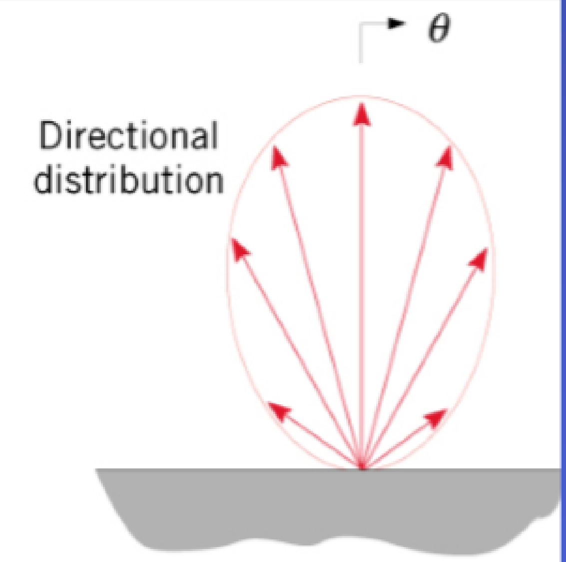
Light is simply the *visible* portion of the electromagnetic spectrum that lies between 0.4 and 0.7 µm.

- Thermal radiation is confined to the infrared, visible and ultraviolet regions of the spectrum $0.1 < \lambda < 100\ \mu m$.

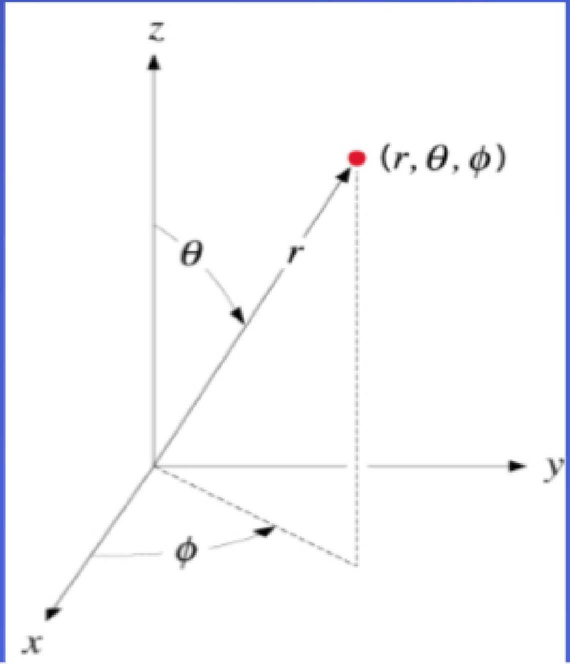
- The amount of radiation emitted by an opaque surface varies with wavelength, and we may speak of the spectral distribution over all wavelengths or of monochromatic/spectral components associated with particular wavelengths.



Directional Considerations and the Concept of Radiation Intensity



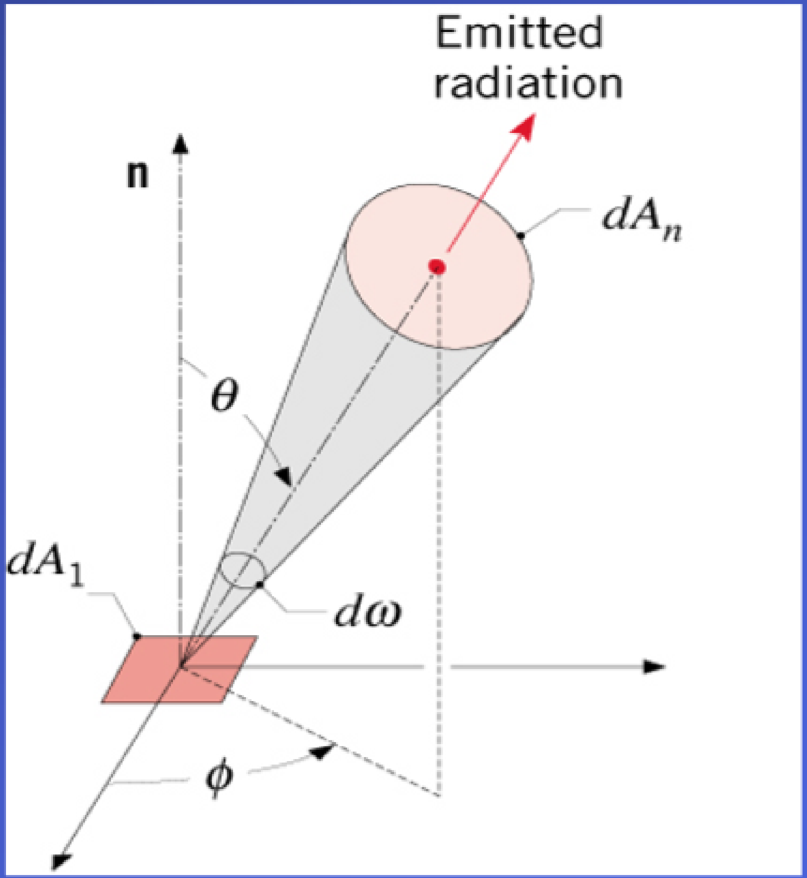
- Radiation emitted by a surface will be in all directions associated with a hypothetical hemisphere about the surface and is characterized by a directional distribution.



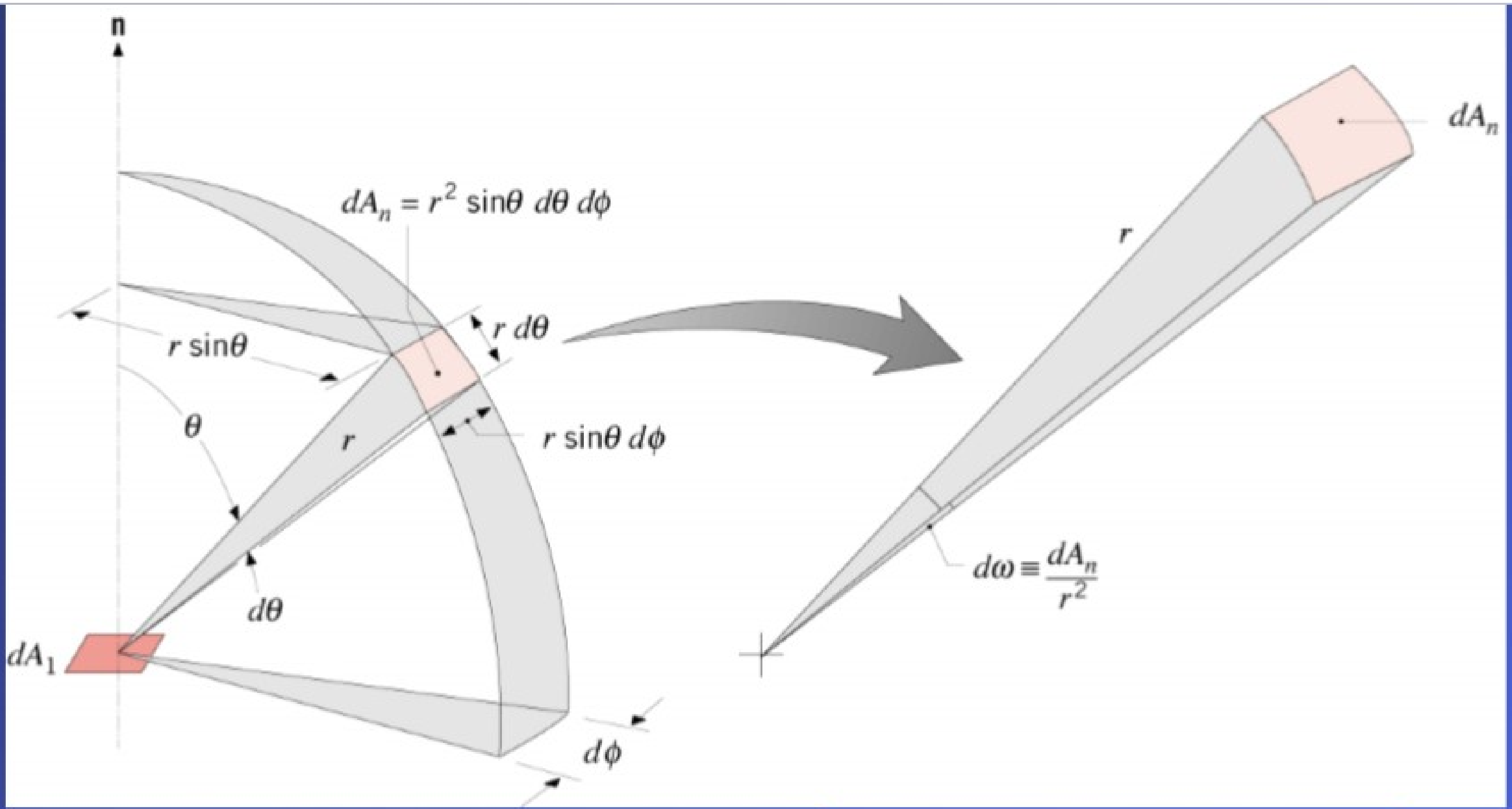
- Direction may be represented in a spherical coordinate system characterized by the zenith or polar angle θ and the azimuthal angle ϕ .

- The amount of radiation emitted from a surface, dA_1, and propagating in a particular direction, θ, ϕ, is quantified in terms of a differential solid angle ($d\omega$) associated with the direction.

$$\boxed{d\omega \equiv \frac{dA_n}{r^2}}$$



$dA_n \rightarrow$ unit element of surface on a hypothetical sphere and normal to the θ, ϕ direction.



$$\boxed{dA_n = r^2 \sin\theta\ d\theta\ d\phi} \qquad \boxed{d\omega \equiv \frac{dA_n}{r^2} = \sin\theta\ d\theta\ d\phi}$$

- The solid angle ω has units of steradians (sr).
- The solid angle associated with a complete hemisphere is

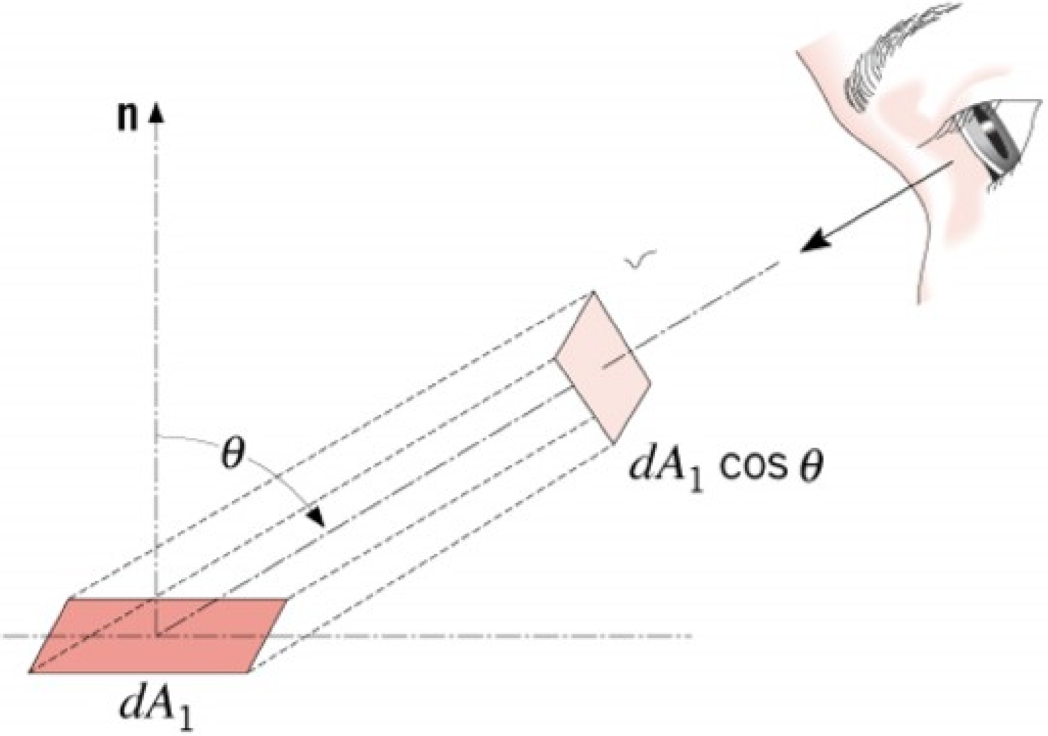
$$\omega_{hemi} = \int_0^{2\pi} \int_0^{\pi/2} \sin\theta\ d\theta\ d\phi = 2\pi \qquad \text{(unit: sr)}$$

- Spectral Intensity:

  A quantity used to specify the radiant heat flux $\left(\mathrm{W/m^2}\right)$ within a unit solid angle about a prescribed direction $\left(\mathrm{W/m^2 \cdot sr}\right)$ and within a unit wavelength interval $\left(\mathrm{W/m^2 \cdot sr \cdot \mu m}\right)$. about a prescribed wavelength

- The spectral intensity $I_{\lambda,e}$ associated with emission from a dA_1 surface element in the solid angle $d\omega$ about θ,ϕ and the wavelength interval $d\lambda$ about λ is defined as:

$$\boxed{I_{\lambda,e}(\lambda,\theta,\phi) \equiv \frac{dq}{(dA_1 \cos\theta)\cdot d\omega \cdot d\lambda}}$$



Formal definition of $I_{\lambda,e}$

The rate at which radiant energy is emitted at the wavelength λ in the (θ, ϕ) direction, per unit area of the emitting surface normal to this direction, per unit solid angle about this direction, and per unit wavelength interval $d\lambda$ about λ.

Thank you