

Nature of Electromagnetic Radiation – 2

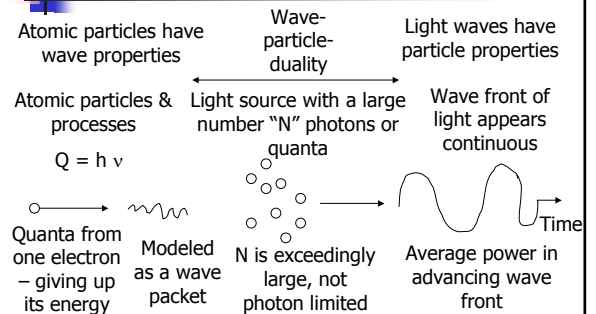
Quantum properties

- Maxwell's formulation – mathematically smooth wave motion of EM – fails to account for certain significant phenomena
 - More evident as wavelength of radiation becomes smaller
 - Generation of EM waves always occurs in short wave trains or bursts of radiation
 - $Q = h \nu$
 - h = Universal or Planck's constant (6.625×10^{-34} joule sec)

Quantum properties

- Radiant energy of these wave trains not delivered to the receiver as spread out evenly over a wave – delivered all at one place on a probabilistic basis
- Rate of energy flow is continuously fluctuating because of quantized & statistical nature of EMR

Quantization of radiation



Quantum properties

- Photon* – emphasizes the quantized & statistical properties of radiation
- Wave* – emphasizes the overall average effects of radiation
- Photon-noise limited* – measurement of radiation lacks precision primarily because of inherent statistical nature of energy delivery

Quantum properties

- Use quantitative radiant flux measurements to infer "how much of what is where"
- Limit to precision of radiant-flux measurements forces a compromise between rapidity of making radiant-flux measurements & the precision of these measurements

Polarization of EMR

- EMR is an electric force field & a magnetic force field
 - Transverse to the direction of propagation; right angles to each other
- EMR produces an electric field in a fixed direction, plane polarized in that direction
 - Electric field of EMR assuming different directions at random – randomly polarized radiation – mostly in optical region

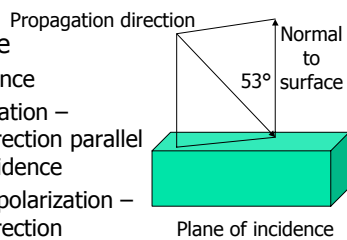
Polarization of EMR – microwave radar

- Plane polarization – polarization direction is parallel to the plane surface upon which the wave is incident – *horizontal polarization*
- Plane polarization that is at right angles to the horizontally polarized direction is called *vertical polarization*

Polarization of EMR

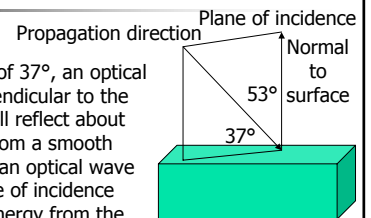
■ Optics literature

- Plane of incidence
- Parallel polarization – polarization direction parallel to plane of incidence
- Perpendicular polarization – polarization direction perpendicular to plane of incidence



Polarization of EMR

- At an incident angle of 37° , an optical wave polarized perpendicular to the plane of incidence will reflect about 7.8% of its energy from a smooth water surface, while an optical wave polarized in the plane of incidence will not reflect any energy from the same surface – all energy will penetrate into the water – called the Brewster effect



Nomenclature

- Information to be used for remote sensing is derived from quantitative measurements of the properties of EMR arriving at a sensor
- Try to use a common nomenclature and symbolism

Radiant energy, Q

- Energy carried by EMR – measure of the capacity of the radiation to do physical work by moving something by a force, to heat an object, or to cause a change of state of matter
- Although radiation is not material, can have *quantities* of radiation
- Radiant energy causes a sensor-detecting element to change physically
- Unit of energy is joule (J)

Radiant flux, ϕ

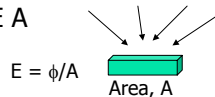
- Time rate with which radiant energy passes a spatial position; flow rate
 - Or time rate of flow of the number of quantized energy (photons) to a detector – *photon flux*
 - Or rate of flow of some visible part of the radiant energy, *luminous flux*
- Joule/second (J s^{-1}) or watt (W)

Radiant flux, ϕ

- $Q = \phi t$ or when ϕ changes from time to time
 - $Q = \int_{t_1}^{t_2} \phi(t) dt$
- Certain minimum amount of energy need for detector to provide evidence that radiant flux was intercepted
- Magnitude of radiant flux at a point is of primary interest because of the limitation on the amount of time
 - $\phi_{\min} = Q_{\min} / t_{\text{allowed}}$

Radiant flux density, E & M

- Radiant flux intercepted by a plane surface, the amount of radiant flux intercepted per unit area of plane surface – *average radiant flux density*
- Radiant flux density for flux incident upon a plane surface – *irradiance*, E (W m^{-2})
- Intercepted flux: $\phi = E A$



Radiant flux density, E & M

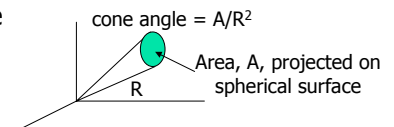
- Flux density of radiant flux leaving a plane surface – *exitance*, M (W m^{-2})
- Directions taken by flux are not specified, so long as it leaves in any or all directions within a hemisphere over the surface

Angular measure

- Degree ($^\circ$): angle subtended by an arc of a circle having $1/360^{\text{th}}$ of the circumference
 - $2\pi r$ – circumference
 - Angle subtended by an arc of length, L , in a circle of radius, r , is L/r
- Radian (rad): angle subtended by an arc of a circle having a length equal to the radius of the circle
 - 2π radians in a full circle

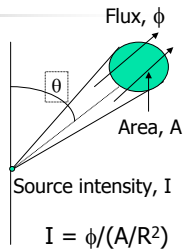
Angular measure

- Steradian (sr): cone angle (solid angle) subtended by a part of a spherical surface of area, A , is A/r^2
- Surface area of sphere is $4\pi R^2$; there are 4 steradians of solid angle in a sphere



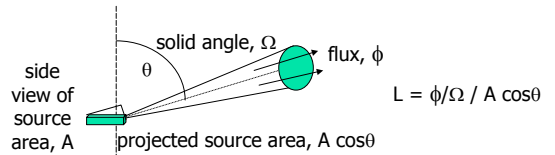
Radiant intensity, I

- Radiant flux per unit solid angle leaving the source in that direction, I (W sr^{-1}), point source
- If a source is isotropic (radiates equally well in all directions), radiant intensity of an isotropic source emitting flux ϕ has radiant intensity, $I = \phi/4\pi \text{ W sr}^{-1}$



Radiance, L

- Radiant flux per unit solid angle leaving an extended source in a given direction per unit projected source area in that direction, L ($\text{W cm}^{-2} \text{ sr}^{-1}$)



Radiance, L

- Plane source for which the radiance, L , does not change as a function of angle of view – Lambertian surface
 - White matte paper, illuminated by diffuse skylight, is a good approximation
 - Perceived visual brightness of paper does not change with angle of view

Spectral quantities

- For quantities – Q , ϕ , M , I , L – consider these for specific spectral bands

Spectral radiant flux, ϕ_λ or ϕ_ν

- How flux is distributed among the components of different wavelengths or frequencies – *spectral distribution*
- Spectral distribution of radiant flux found by measuring the radiant flux in a *narrow wavelength or frequency interval*
- Use spectrographic equipment
 - Wavelength, λ , with wavelength interval, $\Delta\lambda$
 - Measure $\phi[\lambda - \Delta\lambda/2 \text{ to } \lambda + (\Delta\lambda/2)]$

Spectral radiant flux, ϕ_λ or ϕ_ν

- *Spectral radiant flux* – ϕ_λ for wavelength intervals or ϕ_ν for frequency intervals
- $\phi(\lambda_1 \text{ to } \lambda_2) = \int_{\lambda_1}^{\lambda_2} \phi_\lambda(\lambda) d\lambda$

Other spectral quantities

- Q_λ = spectral radiant energy
- ϕ_λ = spectral radiant flux
- E_λ = spectral irradiance
- M_λ = spectral exitance
- I_λ = spectral radiant intensity
- L_λ = spectral radiance

Hemispherical reflectance, transmittance and absorptance

- *Hemispherical reflectance*, ρ – dimensionless ratio of the reflected exitance of a plane of material to the irradiance on that plane
 - $\rho = M_{\text{reflected}} / E$

Hemispherical reflectance, transmittance and absorptance

- *Hemispherical transmittance*, τ – dimensionless ratio of the transmitted exitance, leaving the opposite side of a plane, to the irradiance
 - $\tau = M_{\text{transmitted}} / E$

Hemispherical reflectance, transmittance and absorptance

- *Hemispherical absorptance*, α – dimensionless ratio
 - $\alpha = 1 - \tau - \rho$
- Definitions imply that radiant energy must be conserved
- Incident flux returned back by reflection, transmitted through, or transformed into some other form of energy

Hemispherical reflectance, transmittance and absorptance

- Spectral hemispherical reflectance
 - $\rho(\lambda) = M_{\lambda, \text{reflected}} / E_\lambda$
- Spectral hemispherical transmittance
 - $\tau(\lambda) = M_{\lambda, \text{transmitted}} / E_\lambda$
- Spectral hemispherical absorptance
 - $\alpha(\lambda) = 1 - \rho(\lambda) - \tau(\lambda)$

Measurement of EMR

- Measurement of the quantity, quality & direction of EMR at the position of the observer
 - Radiometric measurement
 - Human visual system is a radiometric system – relies on subconscious inferences connecting certain properties of radiation – direction of flow (shape recognition), category of items or conditions of interest viewed
- Need this extensive & precise system of nomenclature & units – inferential connection between radiometric measurement by a nonvisual system & the category of items