Medical Physics

Lecture_1 : Overview of University Mathematics

The Greek alphabet

A, α	alpha	H, η	eta	N, ν	nu	T, τ	tau
B, β	beta	Θ, θ	theta	Ξ, ξ	xi	Υ, υ	upsilon
Γ, γ	gamma	I, ι	iota	O, o	omicron	Φ, ϕ, φ	phi
Δ, δ	delta	K, κ	kappa	Π, π	pi	X, χ	chi
E, ε, ϵ	epsilon	Λ, λ	lambda	P, ρ, ϱ	rho	Ψ, ψ	psi
Z, ζ	zeta	M, μ	mu	$\Sigma, \sigma, \varsigma$	sigma	Ω, ω	omega

PERCENTAGE ERROR & DEGREE OF ACCURACY

Percent error is the difference between an estimated value and the true or exact value, expressed in percentage.

$$\text{Percentage error} = \frac{|\text{Approximate value} - \text{Exact value}|}{|\text{Exact value}|} \times 100\%$$

PERCENTAGE ERROR & DEGREE OF ACCURACY

Example:

If a student measured the temperature of boiling water to be 98.5°C, the percentage error is:

$$\text{Percentage error} = \frac{|98.5 - 100|}{|100|} \times 100\% = \frac{1.5}{100} \times 100\% = 1.5\%$$

The degree of accuracy & Absolute error

- **Degree of accuracy** is a measure of how exact a stated value is to the actual value being described.
- Accuracy may be <u>affected by</u> rounding, the use of significant figures or ranges in measurement.
- **Absolute error** is the difference between the actual and the measured value (symbol ±).

$$\text{Relative error} = \frac{|\text{absolute error}|}{\text{measured value}}$$

$$\text{Percentage error} = \frac{\text{absolute error}}{\text{measured value}} \times 100\%$$

PERCENTAGE ERROR & DEGREE OF ACCURACY

Example:

A truck is measured as 22.5 meters long, accurate to 0.1 of a meter.

Accurate to 0.1 m means it could be up to $\frac{0.1}{2} = 0.05$ m either way:

Length = 22.5±0.05 m

So it could really be anywhere between 22.45 m and 22.55 m long.

Thus

$$\text{Absolute error} = 0.05$$

$$\text{Relative error} = \frac{0.05}{22.5} \cong 0.002$$

$$\text{Percentage error} = \frac{0.05}{22.5} \times 100\% \cong 0.2\%$$

INDICES

- Indices explain how many copies of the base number are multiplied.

$$a^1 = a$$
$$a^2 = a \times a$$
$$a^n = a \times a \times \ldots n \; times$$

- For example, 25 is a power, where 2 is called the base and 5 is called the index or exponent.
- Descartes in 1637 was the first to use this shorthand definition 24 for 2×2×2×2.

Indices satisfy the following rules:

1) where n is *positive whole* number

$\mathbf{a^n = a \times a \times a \times a \ldots\ldots \mathit{n}\ times}$

e.g. $2^3 = 2 \times 2 \times 2 \ = 8$

2) *Negative* powers…..

$$\mathbf{a^{-n} = \frac{1}{\mathit{a}^{\mathit{n}}}}$$

e.g. $\mathbf{a^{-2}} = \dfrac{1}{\mathbf{a}^2}$

e.g. where a = 2

$2^{-1} = \dfrac{1}{2}$ **or** $2^{-2} = \dfrac{1}{2 \times 2} = \dfrac{1}{4}$

Indices satisfy the following rules:

3) A *Zero* power

$\mathbf{a^0 = 1}$

e.g. $8^0 = 1$

4) A *Fractional* power

$$\boldsymbol{a^{\frac{1}{n}} = \sqrt[n]{a}}$$

e.g.

$$9^{\frac{1}{2}} = \sqrt[2]{9} = \sqrt{9} = 3$$

$$8^{\frac{1}{3}} = \sqrt[3]{8} = 2$$

All indices satisfy the following rules

Rule 1

$$\mathbf{a^m . a^n = a^{m+n}}$$

e.g. $2^2 . 2^3 = 2^5 = 32$

Rule 2

$$\frac{a^m}{a^n} = \mathbf{a^{m-n}}$$

e.g. $\frac{2^3}{2^2} = 2^{3-2} = 2^1 = 2$

All indices satisfy the following rules

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note: if m = n,

then $\dfrac{a^m}{a^n} = \mathbf{a^{m-n} = a^0 = 1}$

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note: $\dfrac{a^m}{a^{-n}} = \mathbf{a^{m-(-n)} = a^{m+n}}$

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note: $\dfrac{a^{-m}}{a^n} = \mathbf{a^{-m-n}} = \dfrac{1}{a^{m+n}}$

All indices satisfy the following rules

Rule 3

$$(a^m)^n = a^{m.n}$$

e.g. $(2^3)^2 = 2^6 = 64$

Rule 4

$$a^n . b^n = (ab)^n$$

e.g. $3^2 \times 4^2 = (3\times4)^2 = 12^2 = 144$

Likewise,

$$\frac{a^n}{b^n} = \left(\frac{a}{b}\right)^n \qquad \text{if } b\neq0$$

e.g.

$$\frac{6^2}{3^2} = \left(\frac{6}{3}\right)^2 = 2^2 = 4$$

INDICES

	Laws of Indices	*Laws of Logarithm*
Zero Exponents	$a^0 = 1$	$\log_a 1 = 0$
Identity	$a^1 = a$	$\log_a a = 1$
Product	$a^m \bullet a^n = a^{m+n}$	$\log_a(m \bullet n) = \log_a(m) + \log_a(n)$
Quotient	$\frac{a^m}{a^n} = a^{m-n}$	$\log_a \frac{m}{n} = \log_a(m) - \log_a(n)$
Negative Exponents	$a^{-n} = \frac{1}{a^n}$	$\log_a \frac{1}{n} = -\log_a n$
Properties of Equality	If $a = b$, $a^n = b^n$	$\log_a(a^n) = n$ *or* $a^{\log_a(n)} = n$

INDICES

Common Base Property of Equality	If $a^m = a^n$, $m = n$	If $\log_a(m) = \log_a(n)$, then $m = n$
Power	$(a^m)^n = a^{m \bullet n}$	$\log_a(m^n) = n \bullet \log_a(m)$
Power of a Product	$(a \bullet \mathrm{b})^m = a^m \mathrm{b}^{\mathrm{m}}$	
Power of a Quotient	$\left(\frac{a}{b}\right)^n = \frac{a^n}{b^n}$	
Rational Exponents	$a^{\frac{m}{n}} = \sqrt[n]{a^m}$	
Change of Base		$\log_a(m) = \frac{\log_x(m)}{\log_x(a)}$

INDICES

Example:

Simplify a) $8^{\frac{2}{3}}$ b) $\sqrt{9^{-3}}$ c) 11^0

SOLUTION tips

a) $8^{\frac{2}{3}} = \left(8^{\frac{1}{3}}\right)^2$

$= \left(\sqrt[3]{8}\right)^2$ $\quad a^{\frac{m}{n}} = \sqrt[n]{a^m}$

$= (2)^2 = 4$

b) $\sqrt{9^{-3}} = \left(\sqrt{9}\right)^{-3}$

$= \frac{1}{(3)^3} = \frac{1}{27}$ $\quad a^{-n} = \frac{1}{a^n}$

c) $11^0 = 1$ $\quad a^0 = 1$

INDICES

Example:

Simplify

a) $(16x^6)^{\frac{1}{2}}$ b) $\left(\frac{3}{4}\right)^{-2}$ c) $30x^5y^4 \div 6xy$

SOLUTION tips

a) $(16x^6)^{\frac{1}{2}} = 16^{\frac{1}{2}} \times (x^6)^{\frac{1}{2}}$

$= 4^{2\times\frac{1}{2}} \times x^{6\times\frac{1}{2}}$ $(a^m)^n = a^{m \cdot n}$

$= 4 \times x^3 = 4x^3$

b) $\left(\frac{3}{4}\right)^{-2} = \left(\frac{4}{3}\right)^2$ $a^{-n} = \frac{1}{a^n}$

$= \frac{4^2}{3^2} = \frac{16}{9}$

c) $30x^5y^4 \div 6xy$

$= \frac{30x^5y^4}{6xy} = \frac{30}{6} \times \frac{x^5}{x} \times \frac{y^4}{y}$

$= 5x^{5-1}y^{4-1}$ $\frac{a^m}{a^n} = a^{m-n}$

$= 5x^4y^3$

LOGARITHMS

- Invented by the Scottish mathematician John Napier, logarithm is the power to which a number must be raised in order to get another number.
- Logarithm is written as “logbx” and read as “log to base b of x”.
- A logarithm is a mirror image of an indices. You can convert an exponential equation into an equivalent logarithmic equation and vice versa.

$$y = \log_b x \text{ is equivalent to } b^y = x.$$
$$2 = \log_{10} 100 \text{ is equivalent to } 10^2 = 100$$

LOGARITHMS

- A Logarithm is a mirror image of an index

If $m = b^n$ then $\log_b m = n$

The log of m to base b is n

If $y = x^n$ then $n = \log_x y$

The log of y to the base x is n

e.g.

$1000 = 10^3$ then $3 = \log_{10} 1000$

$0.01 = 10^{-2}$ then $-2 = \log_{10} 0.01$

LOGARITHMS

- Using Rules of Indices, the following rules of logs apply

1) $\log_b(x \times y) = \log_b x + \log_b y$

eg. $log_{10}(2\times 3) = log_{10} 2 + log_{10} 3$

2) $\log_b \left(\frac{x}{y}\right) = \log_b x - \log_b y$

eg. $log_{10}\left(\frac{3}{2}\right) = log_{10} 3 - log_{10} 2$

3) $\log_b x^m = m.\ \log_b x$

e.g. $log_{10} 3^2 = 2\, log_{10} 3$

LOGARITHMS

- From the above rules, it follows that

(1) $\mathbf{\log_b 1 = 0}$

(since => $1 = b^x$, hence x must=0)

e.g. $\log_{10}1=0$

and therefore,

$$\log_b\left(\frac{1}{x}\right) = -\log_b x$$

e.g. $\log_{10}\left({}^{1}/_{3}\right) = -\log_{10}3$

LOGARITHMS

- From the above rules, it follows that

(2) $$\mathbf{\log_b b = 1}$$

(since => $b = b^x$, hence x must = 1)

e.g. $\log_{10} 10 = 1$

(3) $$\log_b \left(\sqrt[n]{x}\right) = \frac{1}{\mathbf{n}} \log_b x$$

A Note of Caution:

- All logs must be to the same base in applying the rules and solving for values
- The most common base for logarithms are logs to the base 10, or logs to the base e (e = 2.718281…)
- Logs to the base e are called Natural Logarithms

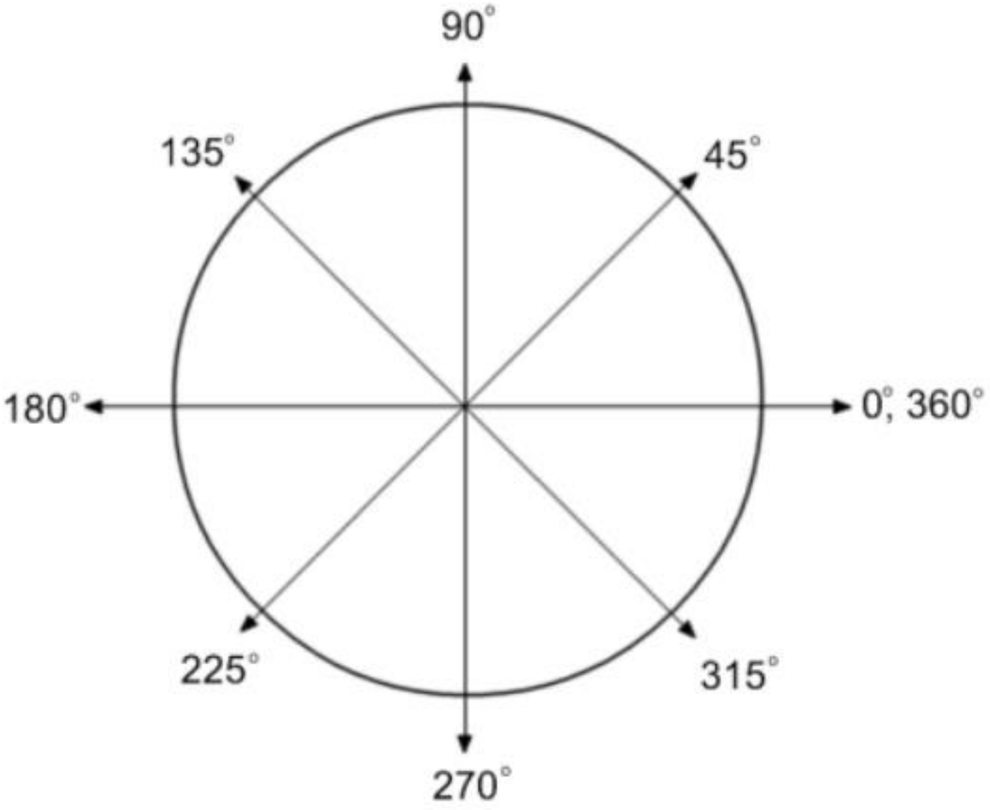
$$\log_e x = \ln x$$

If $y = \exp(x) = e^x$

Then $\log_e y = x$ or $\ln y = x$

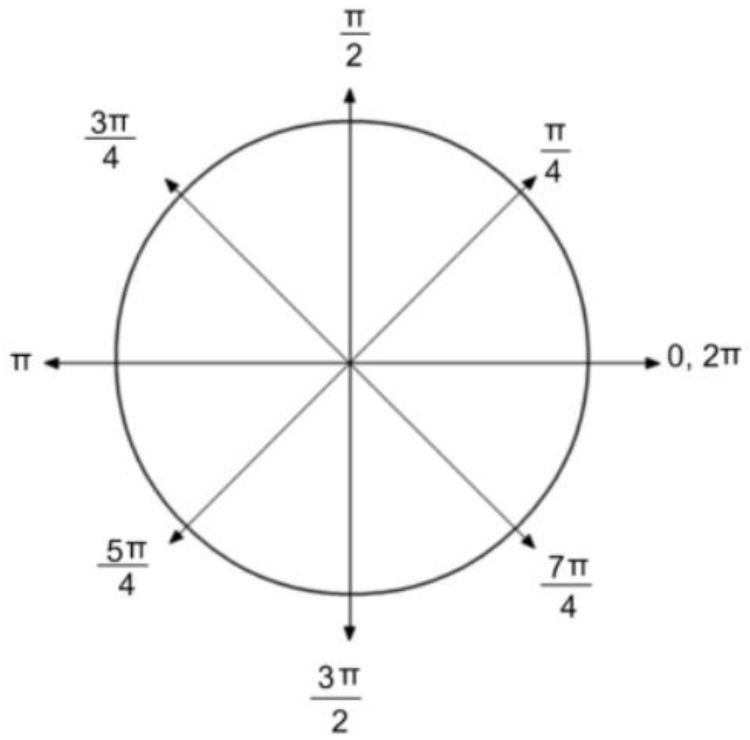
Degrees & Radians

- A circle is comprised of 360°, which is called one revolution.
- Degrees are used primarily to describe the size of an angle.



Degrees & Radians

- The real mathematician is the radian, since most computations are done in radians.
- 1 revolution measured in radians is 2π, where π is the constant approximately 3.14.



How can we convert between the Degrees & Radians

- Easy, since 360° = 2π radians (1 revolution)
- Then, 180° = π radians
- So that means that 1° = $\frac{\pi}{180}$ radians
- And $\frac{180}{\pi}$ degrees = 1 radian

How can we convert between the Degrees & Radians

Example 1

Convert 60° into radians

$$60 \cdot (1 \text{ degree}) \ \frac{\pi}{180} = 60 \cdot \frac{\pi}{180} = \frac{60\pi}{180} = \frac{\pi}{3} \text{ radian}$$

Example 2

Convert (-45°) into radians

$$-45 \cdot \frac{\pi}{180} = \frac{-45\pi}{180} = -\frac{\pi}{4} \text{ radian}$$

How can we convert between the Degrees & Radians

Example 3

Convert $\frac{3\pi}{2}$ radian into degrees

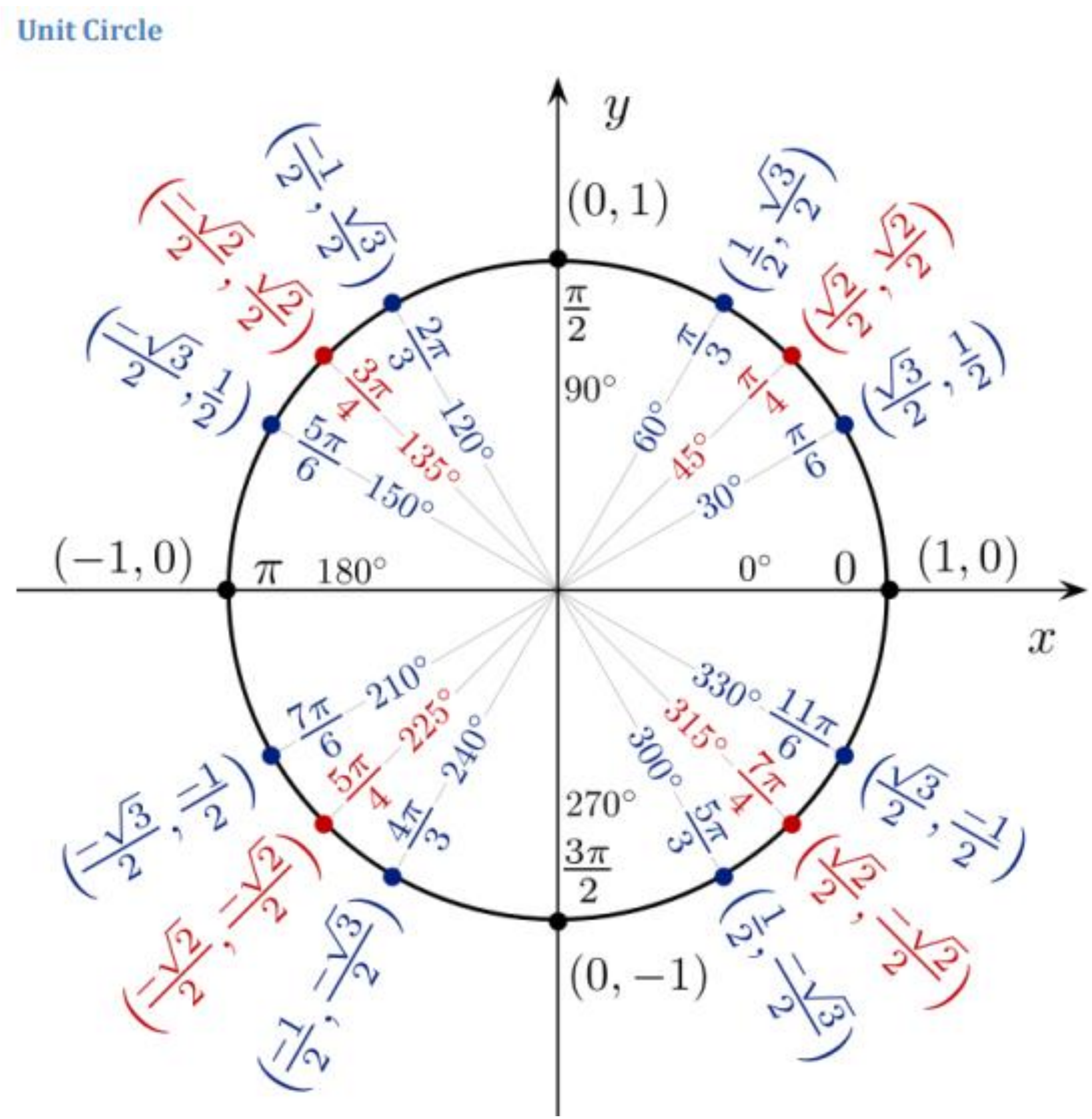
$$\frac{3\pi}{2} \cdot (1 \text{ radian}) \frac{180}{\pi} = \frac{3\pi}{2} \cdot \frac{180}{\pi} = \frac{540\pi}{2\pi} = 270°$$

Example 4

Convert $-\frac{7\pi}{3}$ radian into degrees

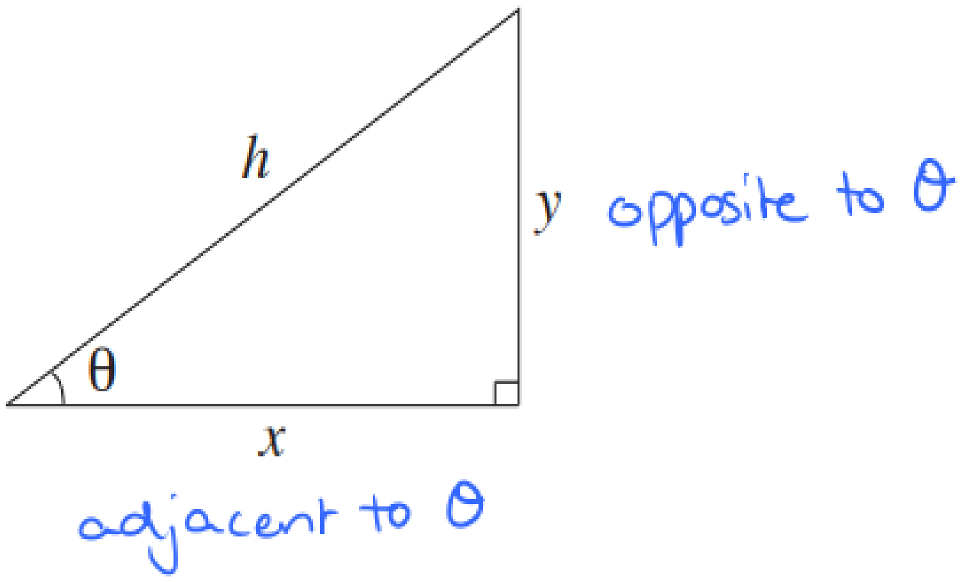
$$-\frac{7\pi}{3} \cdot \frac{180}{\pi} = \frac{1260}{3} = 420°$$

How can we convert between the Degrees & Radians



Trigonometric Functions

Consider a right-angled triangle with angle θ and side lengths x, y and h as shown:

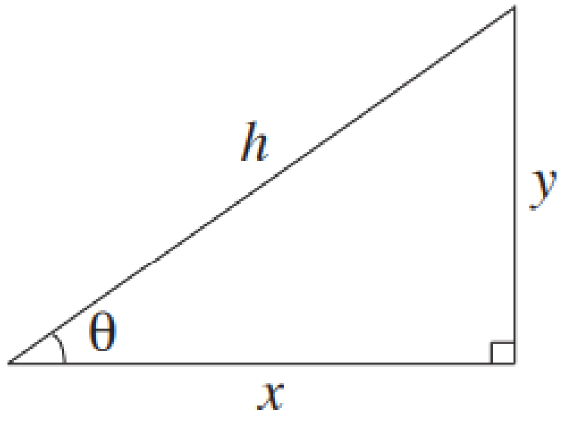


Trigonometric Functions

The trigonometric functions *sine, cosine* and *tangent* of θ are defined as:

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{y}{h}, \qquad \cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{x}{h}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{y}{x} = \frac{\sin\theta}{\cos\theta}$$



opposite to θ

adjacent to θ

Reciprocal Trigonometric Functions

The reciprocal trigonometric functions *secant, cosecant* and *cotangent* are defined as:

$$\sec\theta = \frac{1}{\cos\theta}$$

$$\operatorname{cosec}\theta = \frac{1}{\sin\theta}$$

$$\cot\theta = \frac{1}{\tan\theta} \text{ or } \frac{\cos\theta}{\sin\theta}$$

Functions of negative angles

$$\sin(-\theta) = -\sin\theta, \qquad \operatorname{cosec}(-\theta) = -\operatorname{cosec}\theta$$

$$\cos(-\theta) = \cos\theta$$

$$\tan(-\theta) = -\tan\theta,$$

$$\sec(-\theta) = \sec\theta,$$

$$\cos(-\theta) = \cos\theta$$

$$\cot(-\theta) = -\cot\theta$$

Some formulae regarding compound angles

An angle made up of the sum or differences of two or more angles is called a compound angle.

The basic results in this direction are called trigonometric identies as given below:

(i) $\sin(A+B) = \sin A \cos B + \cos A \sin B$

(ii) $\sin(A-B) = \sin A \cos B - \cos A \sin B$

(iii) $\cos(A+B) = \cos A \cos B - \sin A \sin B$

(iv) $\cos(A-B) = \cos A \cos B + \sin A \sin B$

(v) $\tan(A+B) = \dfrac{\tan A + \tan B}{1 - \tan A \tan B}$

(vi) $\tan(A-B) = \dfrac{\tan A - \tan B}{1 + \tan A \tan B}$

Some formulae regarding compound angles

(vii) $$\cot(A+B) = \frac{\cot A \cot B - 1}{\cot A + \cot B}$$

(viii) $$\cot(A-B) = \frac{\cot A \cot B + 1}{\cot B - \cot A}$$

(ix) $$\sin 2A = 2\sin A\cos A = \frac{2\tan A}{1+\tan^2 A}$$

(x) $$\cos 2A = \cos^2 A - \sin^2 A = 1 - 2\sin^2 A = 2\cos^2 A - 1 = \frac{1-\tan^2 A}{1+\tan^2 A}$$

Home Work-1

Q1: Simplify

1. $(3y^3)^4$
2. $\dfrac{p^3 \times p^5}{(2p)^6}$
3. $-\dfrac{5a^3\text{b} - 3\text{a}b^2}{3b^2 - 5a^2\text{b}}$
4. $\dfrac{3x^7 \times 2x^4}{5x^6}$
5. $\dfrac{y^8}{(y^2)^4}$
6. $-\dfrac{x}{\sqrt{x}}$
7. $\dfrac{35b^3 + 40b^2}{5b^2}$
8. $\dfrac{3b^{-3}(b^2 - 1)}{1 - b -^2}$
9. $\dfrac{24}{\sqrt{2}}\pi\left[\sqrt{\dfrac{1}{8\pi}}\right]^3$

Home Work-1

Q2: Convert the following degree measures into radians

1) 45°	2) 76°	3) 510°	4) -240°	5) 0°
6) 150°	7) 40°	8) 270°	9) 120°	10) 10°
11) 50°	12) -30°	13) 6°	14) 300°	15) -24°

Home Work-1

Q3: Convert the following radian measures into degrees

16) $\frac{7\pi}{3}$

17) $\frac{\pi}{6}$

18) $\frac{\pi}{18}$

19) $\frac{3\pi}{4}$

20) $-\frac{13\pi}{4}$

21) π

22) $\frac{7\pi}{4}$

23) $-\frac{17\pi}{4}$

24) 2π

25) $\frac{\pi}{3}$

26) $\frac{2\pi}{3}$

27) $-\frac{\pi}{4}$

28) 0

29) $\frac{5\pi}{4}$

30) 3π

Questions

Medical Physics

Lecture_2 : Electromagnetic Waves & Spectrum

Waves

- The concept of a wave is something very difficult to find a clear definition in the literature.
- It is important that we have a good understanding of what we mean by a wave.
- Water waves are something that most of us have experienced and that exhibit many of the important features of waves and their propagation.

Waves

- As children, we have nearly all generated waves by throwing stones into a pond.
- Before the stone lands, the surface of the pond (the propagation medium) is calm.
- After impact, however, there is a ripple that travels radially outward from the point of impact.
- The ripple forms a circular band of disturbance that expands at a finite speed.

Waves

- Within the band the ripple maintains its shape but with amplitude that reduces as the radius of the band increases.
- As the ripple travels outward, it might encounter a floating object and then cause it to bob up and down.
- This motion can be used to extract energy from the wave, energy that was originally supplied by the stone's impact (the wave source).
- Further, the vertical motion of the object provides a means of detecting the passage of a wave.

Water waves as a wave phenomena

- First, the wave can transport energy from one point (the source) to another point (the detector), where the energy being transported at a finite speed.
- Second, after the passage of the wave, the medium returns to its undisturbed state.

- This last point leads on to another important property of wave phenomena, the ability to make arbitrarily shaped waves.
- We could simply drive the water up and down by a sequence of impacts of varying force.

Electromagnetic Wave

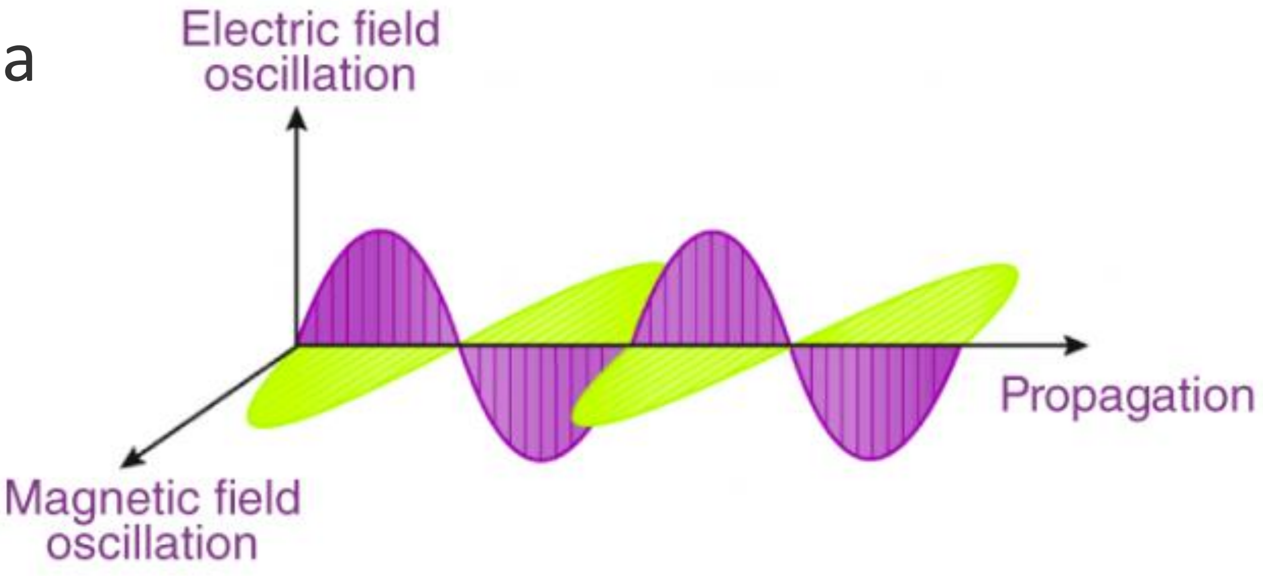
- Electromagnetic waves are also known as **EM waves**.
- Electromagnetic waves are produced when an electric field comes in contact with the magnetic field.
- electromagnetic waves are the composition of oscillating electric and magnetic fields.
- Electromagnetic waves are solutions of Maxwell's equations.

Graphical Representation of Electromagnetic Wave

Electromagnetic wave consists of time-varying electric and magnetic fields which are perpendicular to each other and are also perpendicular to the direction of propagation of waves.

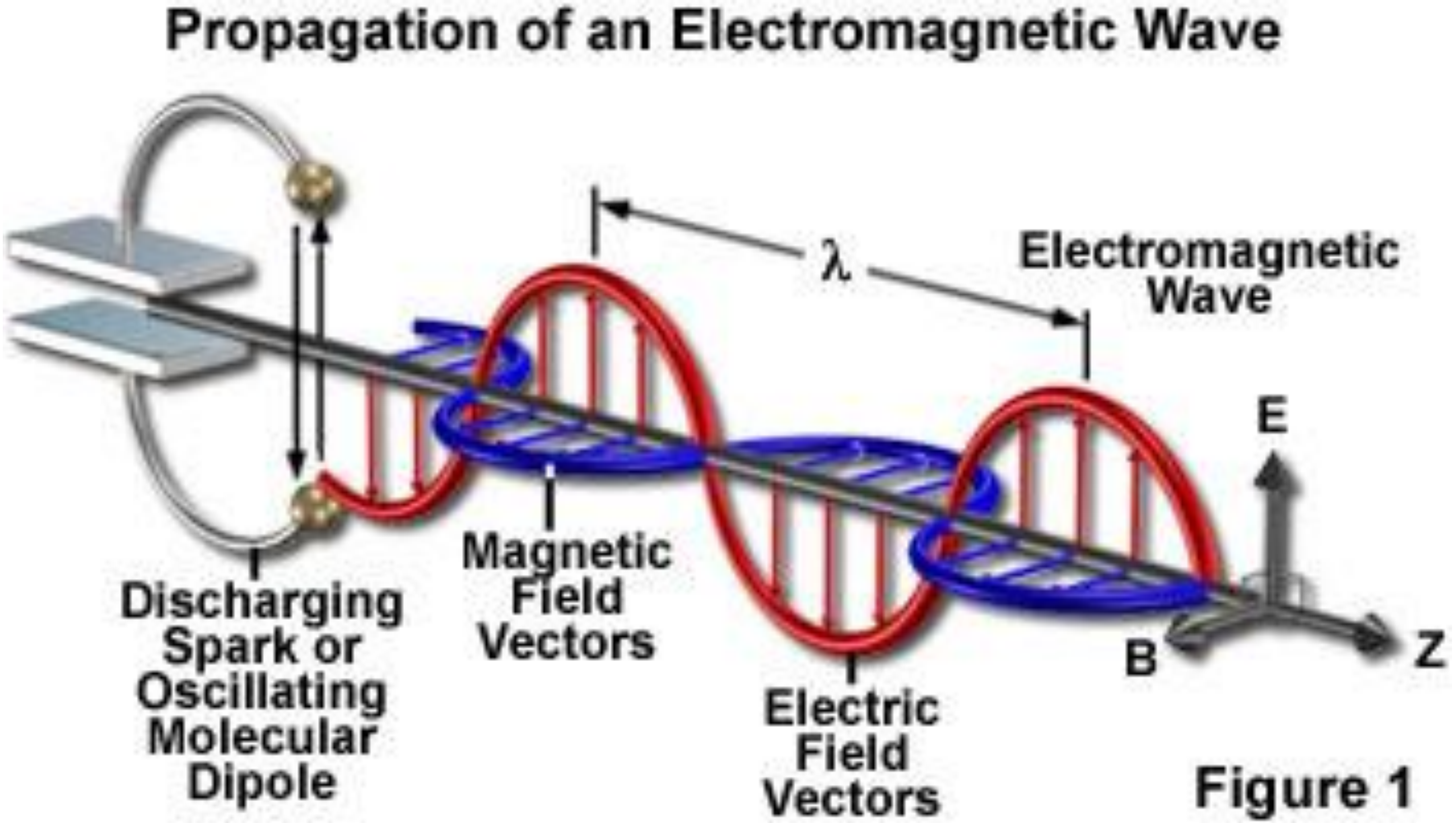
Electromagnetic waves are transverse in nature.

In vacuum, the waves travel at a constant velocity of 3×10^8 m.s^{-1}.



How the Electromagnetic Wave was formed?

- The electric field is produced by a charged particle. Positive charges accelerate in the direction of the field and negative charges accelerate in a direction opposite to the direction of the field.
- The Magnetic field is produced by a <u>moving</u> charged particle. The force on these charges is always perpendicular to the direction of their velocity and therefore only changes the direction of the velocity, not the speed.


Propagation of an Electromagnetic Wave
λ
Electromagnetic Wave
E
Magnetic Field Vectors
Discharging Spark or Oscillating Molecular Dipole
Electric Field Vectors
B
Z
Figure 1

Propagation of Electromagnetic Waves

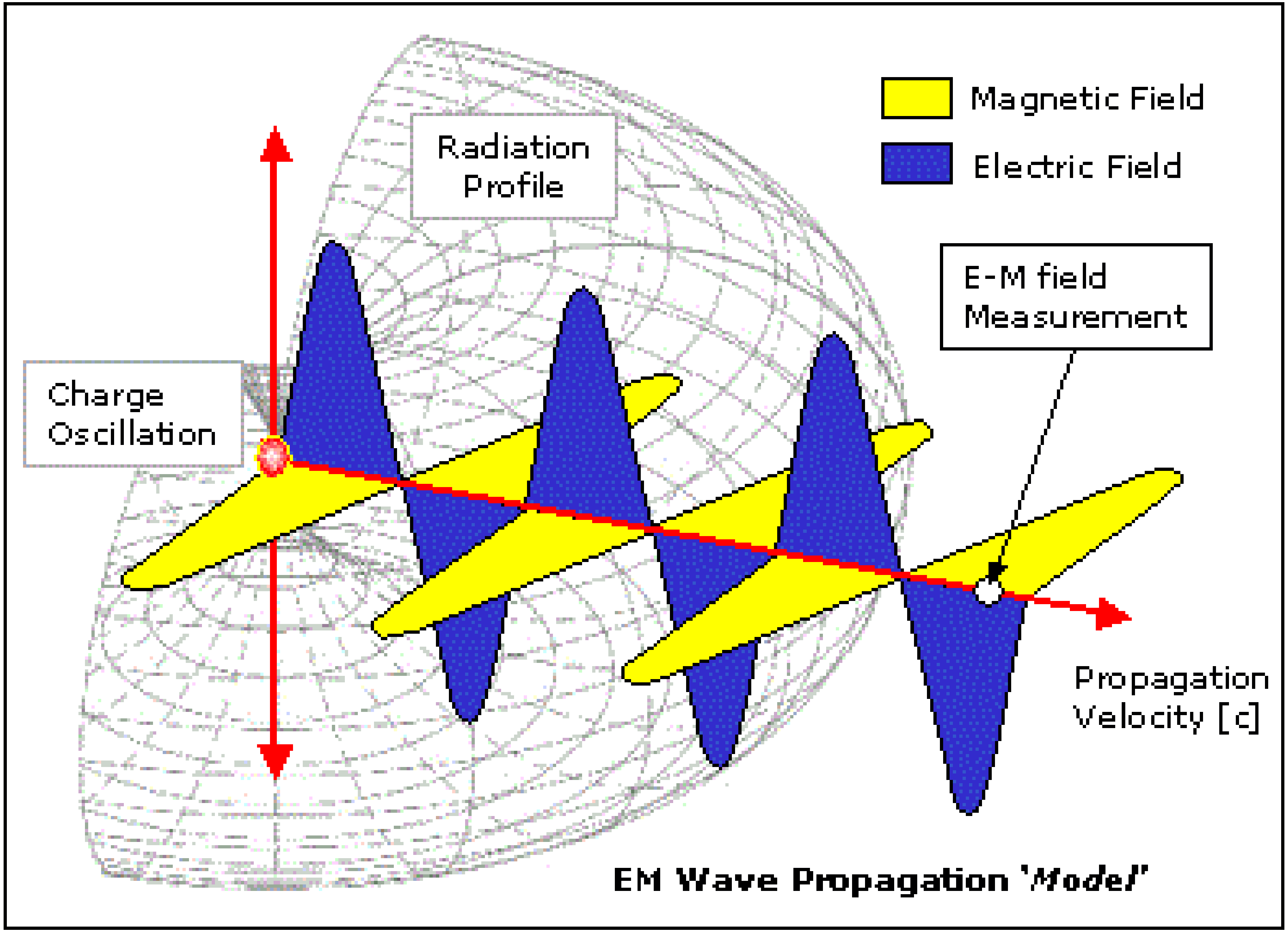
- In last figure, the electromagnetic wave has been generated by a discharging capacitor or an oscillating molecular dipole.
- The spark current oscillates at a **frequency** (**ν**).
- The electromagnetic disturbance that results is propagated with the **electric** (**E**) and **magnetic** (**B**) vectors vibrating perpendicularly to each other and also to the direction of propagation (Z).
- The **frequency** (**ν**), is determined by the oscillator.
- The **wavelength** (**λ**) is determined by the oscillation frequency and the velocity of the electromagnetic wave.

Propagation of Electromagnetic Waves

- As the **current oscillates** up and down in the spark gap, at the characteristic circuit **frequency** (ν), a magnetic field is created that oscillates in a horizontal plane.
- The **changing magnetic field**, in turn, induces an electric field so that a series of electrical and magnetic oscillations combine to produce a formation that propagates as an electromagnetic wave.

Propagation of Electromagnetic Waves

- The electric field in an electromagnetic wave vibrates with its vectorial force growing stronger and then weaker, alternating in a sinusoidal pattern.
- At the same frequency, the magnetic field oscillates perpendicular to the electric field.
- The electric and magnetic are **perpendicular to each other** and **perpendicular to the direction of wave propagation**.


Magnetic Field
Electric Field
Radiation Profile
E-M field Measurement
Charge Oscillation
Propagation Velocity [c]
EM Wave Propagation 'Model'

Propagation of Electromagnetic Wave

Properties of propagation of electromagnetic waves:

- These waves travel at the speed of light.
- For propagation of these waves medium is not required.
- These waves undergo interference and diffraction and can be polarized.
- These waves do not get deflected by an electric or magnetic field.
- These waves travel in transverse form.

Propagation of Electromagnetic Waves

- Radiating systems must operate in a complex changing environment that interacts with propagating electromagnetic waves.
- Commonly observed propagation effects on waves are: reflection, refraction, diffraction, attenuation, scattering, and depolarization.

Characteristics of Electromagnetic Wave

- Electromagnetic wave propagation does not require any material medium to travel.
- The inherent characteristic of an electromagnetic wave is its frequency.
- Electromagnetic wave frequencies remain unchanged but its wavelength changes when the wave travels from one medium to another.

Electromagnetic Wave Velocity

- Electromagnetic waves are travelling through free space with the speed of light c.
- If the frequency of oscillation of the charged particle is f, then it produces an electromagnetic wave with frequency f.
- The wavelength λ of this wave is given by $\lambda = \frac{c}{f}$

Velocity of Electromagnetic Wave

It is given by

$$C = \frac{1}{\sqrt{(\mu_0 \epsilon_0)}}$$

Where,

μ_0 is called absolute permeability. It's value is $1.257 \times 10^{-6} TmA^{-1}$

ϵ_0 is called absolute permittivity. It's value is $8.854 \times 10^{-12} C^2 N^{-1} m^{-2}$

C is the velocity of light in vacuum = velocity of electromagnetic waves in free space = $3 \times 10^8 ms^{-1}$

Energy Formula of Electromagnetic Radiation

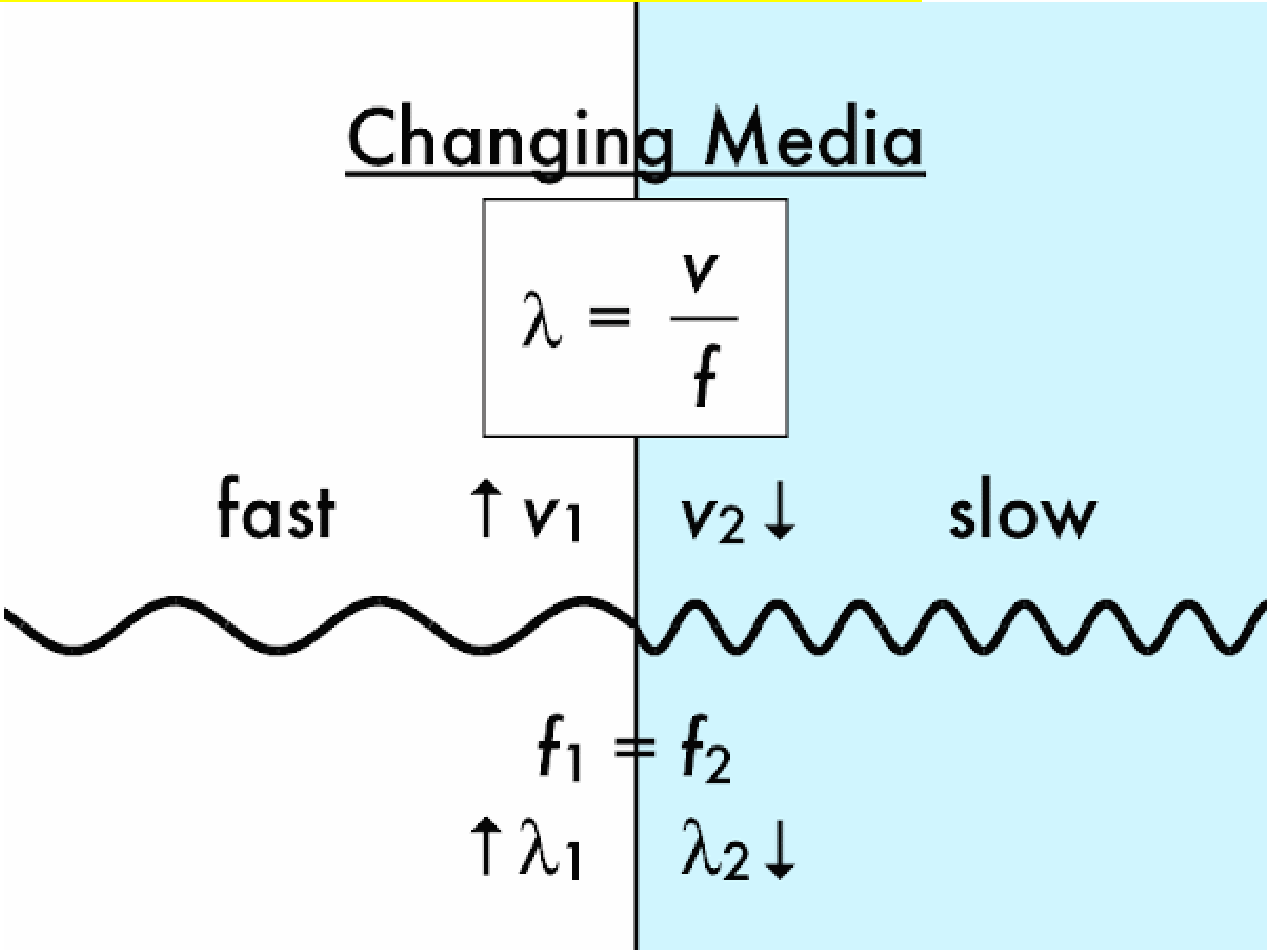
The frequency(f), speed(c), energy(E), wavelength(λ) of electromagnetic waves are related as:

$$f = \frac{c}{\lambda}, \quad \text{or} \quad f = \frac{E}{h}, \quad \text{or} \quad E = \frac{hc}{\lambda},$$

where:

- c = 299792458 m/s is the speed of light in a vacuum
- $h = 6.62607015 \times 10^{-34}$ J·s = $4.13566733(10) \times 10^{-15}$ eV·s is Planck's constant.

Change the medium on EM velocity



Electromagnetic Spectrum

- Electromagnetic spectrum is defined as the range of all types of electromagnetic radiation.
- The electromagnetic spectrum is a range of frequencies, wavelengths and photon energies.
- electromagnetic spectrum is covering frequencies from **below 1Hz** to above **10^{25}Hz**, and the corresponding wavelengths which are a few kilometres to a fraction of the size of an atomic nucleus.

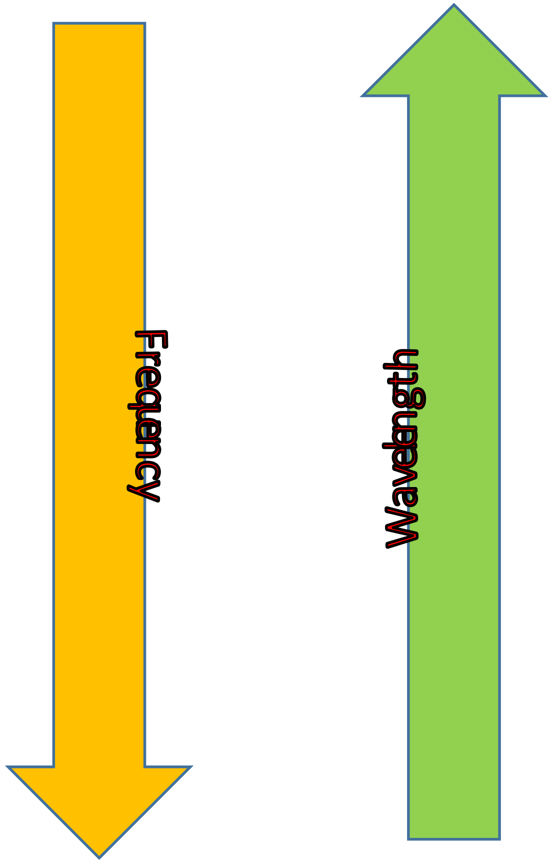
Electromagnetic Spectrum

- The electromagnetic spectrum consists of many subranges which are called spectrum portions.
- Those portions in sequence are in the increasing order of frequency and decreasing order of wavelength.

Electromagnetic Spectrum

- Spectrum portions can be classified as in sequence (order) as:

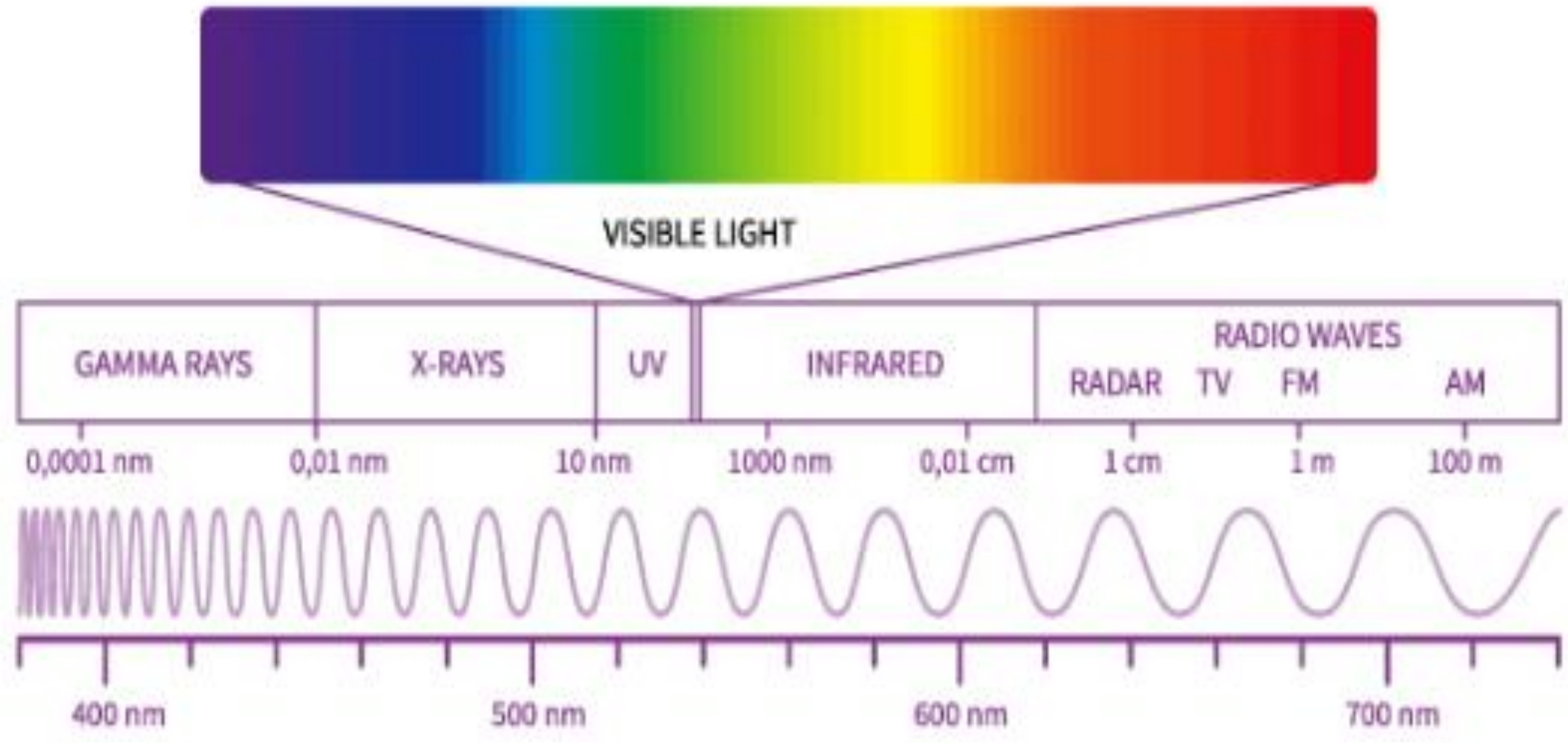
1. radio waves,
2. microwaves,
3. infrared radiation,
4. visible light,
5. ultra-violet radiation,
6. X-rays,
7. gamma rays.

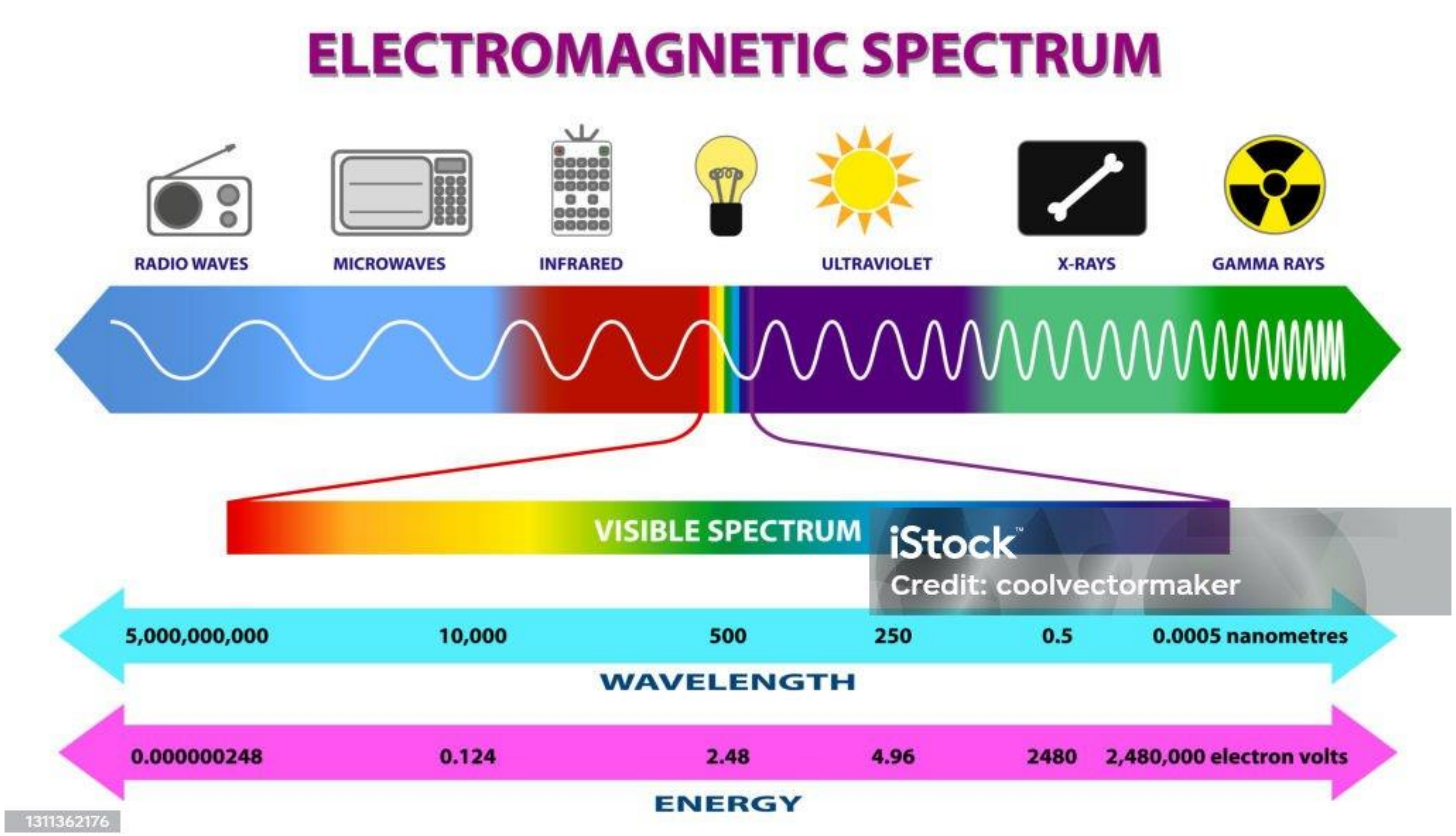


Electromagnetic Spectrum

Type of Radiation	Frequency Range (Hz)	Wavelength Range
gamma-rays	$10^{20} – 10^{24}$	$< 10^{-12}$ m
x-rays	$10^{17} – 10^{20}$	1 nm – 1 pm
ultraviolet	$10^{15} – 10^{17}$	400 nm – 1 nm
visible	$4 \times 10^{14} – 7.5 \times 10^{14}$	750 nm – 400 nm
near-infrared	$1 \times 10^{14} – 4 \times 10^{14}$	2.5 μm – 750 nm
infrared	$10^{13} – 10^{14}$	25 μm – 2.5 μm
microwaves	$3 \times 10^{11} – 10^{13}$	1 mm – 25 μm
radio waves	$< 3 \times 10^{11}$	> 1 mm

Electromagnetic Spectrum




ELECTROMAGNETIC SPECTRUM
RADIO WAVES
MICROWAVES
INFRARED
ULTRAVIOLET
X-RAYS
GAMMA RAYS
VISIBLE SPECTRUM
5,000,000,000
10,000
500
250
0.5
0.0005 nanometres
WAVELENGTH
0.000000248
0.124
2.48
4.96
2480
2,480,000 electron volts
ENERGY

Practical Applications of the Electromagnetic Waves

- The radio waves and microwaves discovered by Hertz, who paved the way for wireless communication.
- Radio wave are transmitted by radio stations. Radio waves can also be emitted by gases and stars in space. Radio waves are mainly used for TV/mobile communication.
- Microwave: This type of radiation is found in microwaves and helps in cooking at home/office. It is also used by astronomers to determine and understand the structure of nearby galaxies and stars.

Electromagnetic Spectrum

- Infrared: It is used widely in night vision goggles. These devices can read and capture the infrared light emitted by our skin and objects with heat. In space, infrared light helps to map the interstellar dust.
- The visible light portion of the electromagnetic spectrum is the reason for all visual aids in daily life. This portion of the electromagnetic spectrum that helps us to see all the objects, including the colors.

Practical Applications of the Electromagnetic Waves

- The ultraviolet radiation has energies to ionize the atoms causing chemical reactions.
- The X-rays discovered by Roentgen, who proved to be useful in medicine for detecting diseases or deformities in bones.
- X-ray: X-rays can be used in many instances. For example, a doctor can use an x-ray machine to take an image of our bone or teeth. Airport security personnel use it to see through and check bags. X-rays are also given out by hot gases in the universe.

Electromagnetic Spectrum

- The gamma rays discovered by Paul Villard are useful for ionization purposes, and for nuclear medicine.
- Gamma-ray: It has a wide application in the medical field. Gamma-ray imaging is used to see inside our bodies. Interestingly, the universe is the biggest gamma-ray generator of all.

Questions

Medical Physics

Lecture_3 : Introduction to Light

Introduction to Light

- Light **is basic to** almost all life on Earth.
- Light **is a form of** electromagnetic radiation.
- Light **represents** energy transfer from the source to the observer.
- Many phenomena depend on the properties of light.
  - Seeing a TV or computer monitor
  - Blue sky, colors at sunset and sunrise
  - Images in mirrors
  - Eyeglasses and contacts
  - Rainbows

Light Nature Theories

- Though the light has been in existence since the existence of the sun, the effects of light were not discovered much later.
- There are main theories to explain light nature:
  - ✓ Particle Theory
  - ✓ Wave Theory
  - ✓ Electromagnetic Wave Theory
  - ✓ Quantum Theory

Light Nature Theories

- **Particle Theory**: This theory was given in the seventeenth century by Sir Isaac Newton, which states *that light emitted by luminous objects consists of tiny particles of matter called* ***corpuscles****. This particle when hit the surface, each particle is reflected back. The velocity of light changes with the change in density of the medium*.
- This theory could explain three main phenomena of light: the reflection, refraction, and rectilinear propagation of light.

Light Nature Theories

- **Wave Theory**: This theory was discovered by Christian Huygens in the seventeenth century. This theory states that *light is emitted in a series of waves that spread out from a light source in all directions. These waves are not affected by gravity. Then, light waves are mechanical and transverse in nature.*
- This theory successfully explains the reflection, refraction, interference, and diffraction phenomenon of light.

Light Nature Theories

- Electromagnetic Wave Theory: This theory was discovered in the nineteenth century by James Maxwell.
- This theory states that *light waves do not require any medium for transmission. Light waves possess both electrical and magnetic properties and can travel through a vacuum. At any instant of time electric and magnetic fields are perpendicular to each other and also perpendicular to the direction of light.*

Light Nature Theories

- This theory <u>could explain</u> that the electromagnetic wave is a transverse wave. At every point in the wave at a given point of time, the electric and magnetic field strengths are equal. The velocity of the waves depends on the electric and magnetic properties of the medium.

Light Nature Theories

- **Quantum Theory**: The quantum theory of light was proposed by Einstein.
- This theory states that *the light travels in bundles of energy, and each bundle is known as a* ***photon****. Each photon carries a quantity of energy equal to the product of the frequency of vibration of that photon and Planck's constant.*

$$E_{photon} = h\nu$$

The Nature of Light

- Before the beginning of the nineteenth century, light was considered to be a stream of particles.
- The particles were either emitted by the object being viewed or emanated from the eyes of the viewer.
- Newton was the chief architect of the particle theory of light.
- Newton believed the particles left the object and stimulated the sense of sight upon entering the eyes.

The Nature of Light

- Christian Huygens argued that light might be some sort of a wave motion.
- Thomas Young (in 1801) provided the first clear demonstration of the wave nature of light.
- Thomas Young showed that light rays interfere with each other.
- Such behavior could not be explained by particles.

Confirmation of Wave Nature

- During the nineteenth century, other developments led to the general acceptance of the wave theory of light.
- Thomas Young provided evidence that light rays interfere with one another according to the principle of superposition.
- This behavior could not be explained by a particle theory.
- Maxwell asserted that light was a form of high-frequency electromagnetic wave.
- Hertz confirmed Maxwell's predictions.

Light Nature - Particle Nature

- Some experiments **could not be explained** by the wave model of light.
- The photoelectric effect was a major phenomenon not explained by waves.
- When light strikes a metal surface, electrons are sometimes ejected from the surface.
- The kinetic energy of the ejected electron is independent of the frequency of the light.

Light Nature

- Einstein (in 1905) proposed an explanation of the photoelectric effect that used the idea of **quantization**.
- The **quantization model** assumes that the energy of a light wave is present in particles called **photons**.

$$\boldsymbol{E} = \boldsymbol{h} \times \nu$$

$\boldsymbol{h}$ is Planck’s Constant and = $6.63\ x\ 10^{-34}$ J.s

Light Nature - Dual Nature

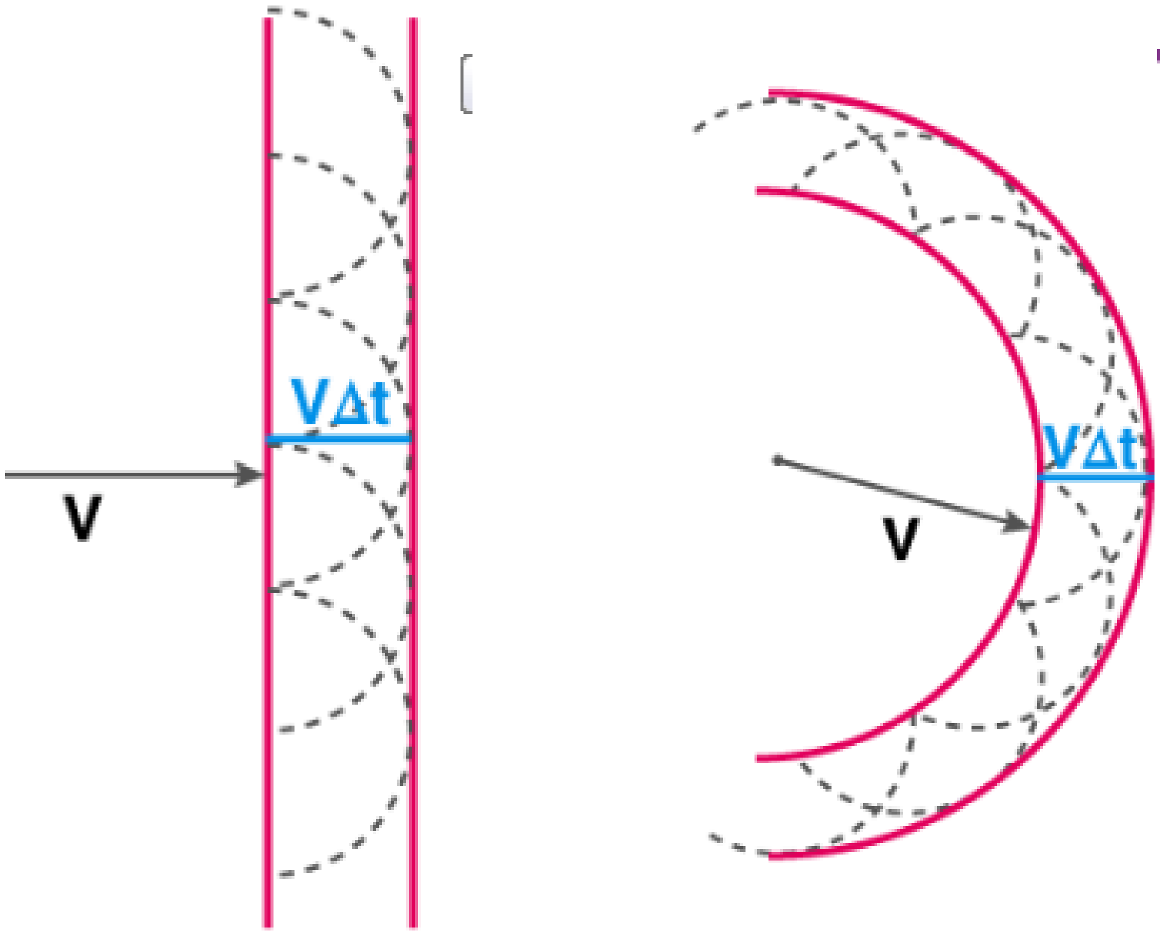
- In view of these developments, light must be regarded as having a **dual nature**.
- The dual nature theory states that *light exhibits the characteristics of a wave in some situations and the characteristics of a particle in other situations.*

Huygens wave theory

- In 1678, Huygens states that :“Every point on a wavefront is in itself the source of spherical wavelets which spread out in the forward direction at the speed of light. The sum of these spherical wavelets forms the wave front”.
- This theory of light is known as the ‘Huygens’ Principle’.
- Huygens successfully derives the laws of reflection and refraction of light. He was also successful in explaining the linear and spherical propagation of light using this theory.

Primary and Secondary Sources

- Huygens stated that light is a wave propagating through space like ripples in water or sound in air. Hence, light spreads out like a wave in all directions from a source.
- The locus of points that travelled some distance during a fixed time interval is called a **wavefront**.



Primary and Secondary Sources

- After the primary wavefront is created, a secondary wavefront is created from every primary wavefront.
- Secondly, every point on the wavefront acts as a secondary source of light that emits more wavefronts.
- This way, a light wave propagates through space by generating secondary sources and wavefronts. The net effect is that the effective wavefront generated is tangential to all the secondary wavefronts generated by the secondary sources. The direction of the traverse is always perpendicular to the wavefronts.

Advantages and Disadvantages of Huygens Principle

- **Advantages**:
  1. Huygens concept proved the reflection and refraction of light.
  2. The concepts like diffraction and interference of light, were proved by Huygens.
- **Disadvantage**:
  1. Concepts like emission of light, absorption of light and polarization of light were not explained by Huygens principle.
  2. Huygens principle failed to explain the photoelectric effect.
  3. A serious drawback is that the theory proposes an all-pervading medium required to propagate light called aluminiferous ether. This was proved to be false in the 20th century.

Visible light spectrum

- The visible light spectrum is the segment of the electromagnetic spectrum that the human eye can view.
- More simply, this range of wavelengths is called visible light.
- Typically, the human eye can detect wavelengths from 380 to 700 nanometers.

WAVELENGTHS OF VISIBLE LIGHT

- All electromagnetic radiation is light, but we can only see a small portion of this radiation, which is visible light.
- Cone-shaped cells in our eyes act as receivers tuned to the wavelengths in this narrow band of the spectrum.
- Other portions of the spectrum have wavelengths too large or too small and energetic for the biological limitations of our perception.

Wavelength and Color Spectrum Chart

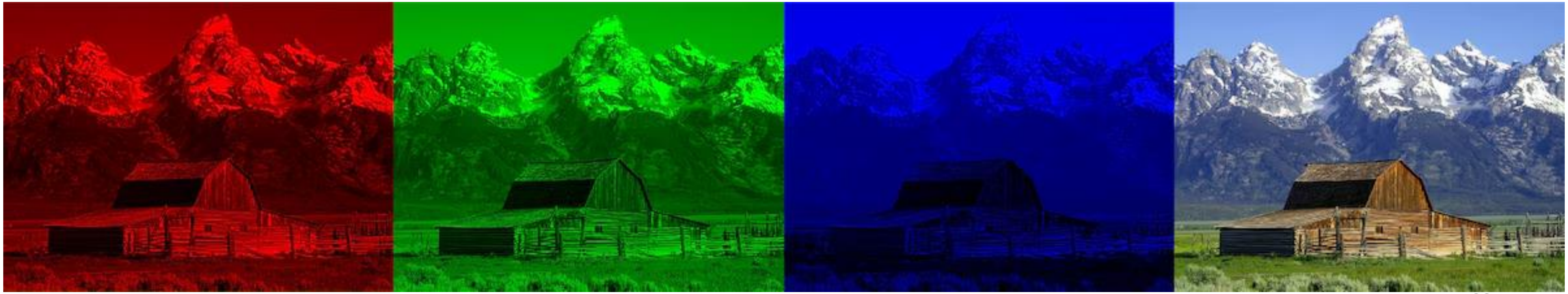
Color	Wavelength (nm)
Red	625 - 740
Orange	590 - 625
Yellow	565 - 590
Green	520 - 565
Cyan	500 - 520
Blue	435 - 500
Violet	380 - 435

Additive Color

- Cameras, televisions, phones and computer monitors use the additive color model.
- The additive color model describes how light produces color. The additive colors are red, green and blue, or **RGB**.
- Additive color starts with black and adds red, green and blue light to produce the visible spectrum of colors.
- As more color is added, the result becomes lighter.
- When all three colors are combined equally, the result is white light.

Additive Color

- These elements are called sub-pixels.
- By combining the three colors, the desired hue is created in one pixel.
- The pixels then come together like tiny mosaics to create a picture.
- Hence, the unit of measurement for a digital graphic is **pixels per inch**.



Subtractive Color

- In the subtractive color model, pigment produces color using reflected light.
- This color model is used in printing, silk-screening, painting.
- The subtractive colors are cyan, yellow, magenta and black, also known as **CMYK**.
- Adding equal amounts of cyan, yellow and magenta will produce black, but in reality, the result is often a very muddy dark brown.

Subtractive Color

- On a piece of paper, cyan, magenta, yellow and black pigments are distributed by the print head in tints.
- A tint is a screen of tiny dots appearing as a percentage of one color.
- The overlapping dots create the illusion of a hue.
- The overlapping patterns create a picture.
- The unit of measurement for a print graphic is **dots per inch**.

Questions

Medical Physics

Lecture_4 : Light as electromagnetic oscillation

Oscillations and Waves

- Oscillation is defined as the periodic fluctuation.
- The back and forth movement of the clock's pendulum is an example of oscillation.
- When the pendulum reaches one of the ends, it has potential energy and is ready to fall.
- When the pendulum is in the middle potential energy gets converted into kinetic energy.
- The potential energy and kinetic energy of the pendulum is converted into those two forms.
- This cycle continues causing oscillation in the pendulum.

Waves

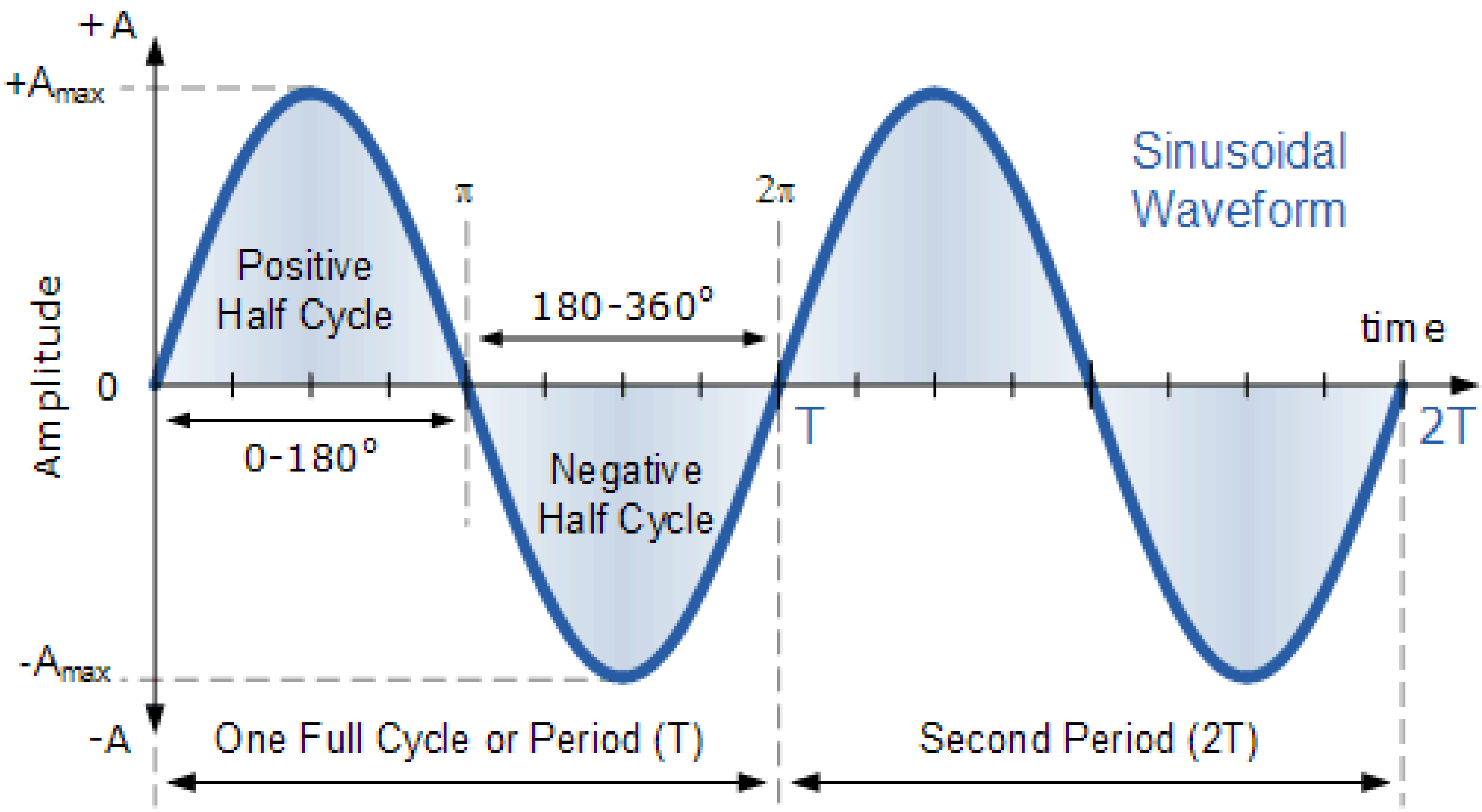
- ✓ A wave is a disturbance.
- ✓ Unlike water waves, electromagnetic waves cannot be seen directly but they have similar characteristics.
- ✓ All periodic waves can be constructed from **sine waves**, which is why sine waves are fundamental.

Important definitions

- **Waveform**

A waveform is a representation of a signal in the form of a wave, showing how the signal varies with time.

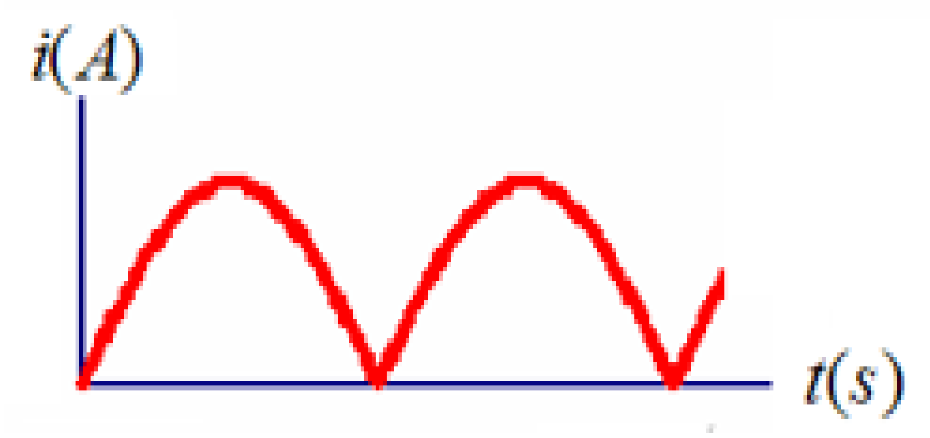
It is a graphical representation that depicts the changes in amplitude of the signal over time.



Important definitions

- **Periodic waveform**

It is a waveform that repeats itself after a certain equal time intervals.



- **Oscillating Value**

It is a value which alternately increases and decreases in magnitude with respect to time.

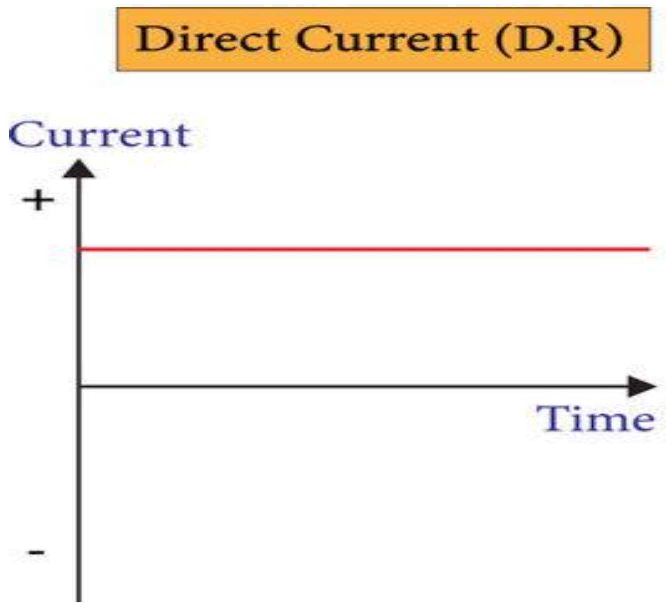
Important definitions

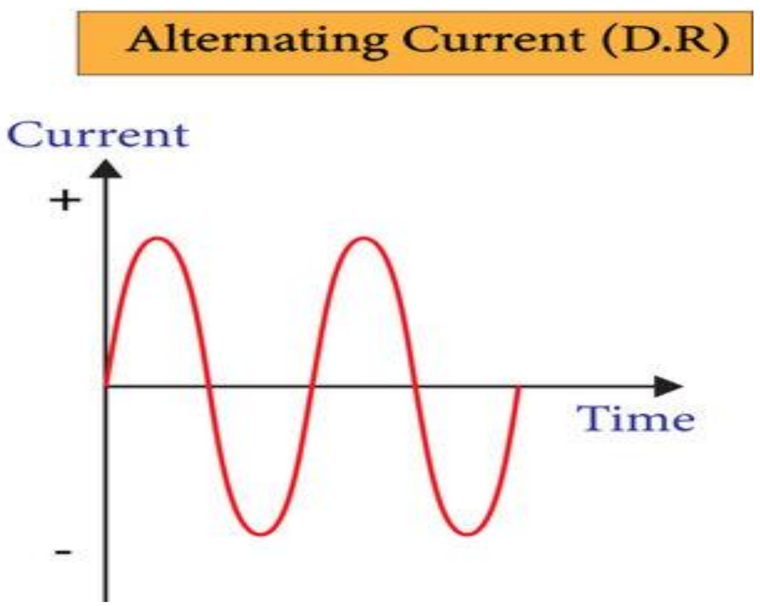
- **Alternating value**

It is a value of periodic waveform that has average value in a period is zero.

- **Dc quantity**

It is a quantity whose value and polarity is not changing.



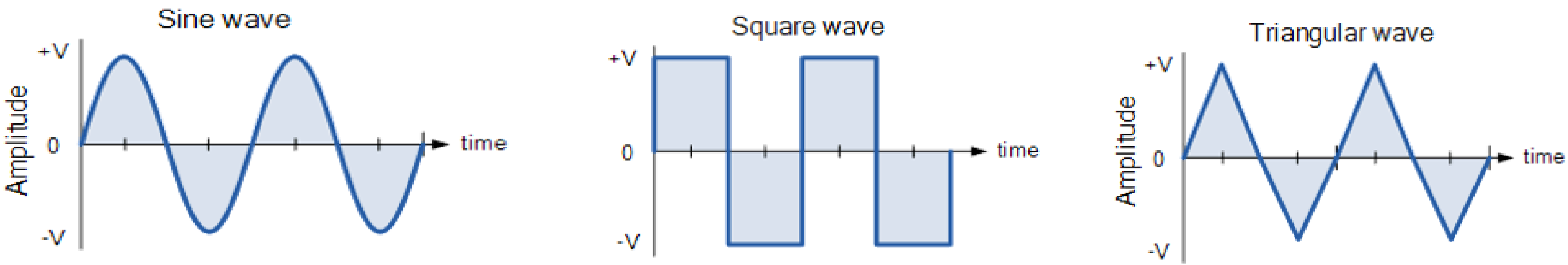


Important definitions

- **Instantaneous value**

It is a value of AC quantity at any instant of time.

Different types of waveforms exist



- **Period (T)**

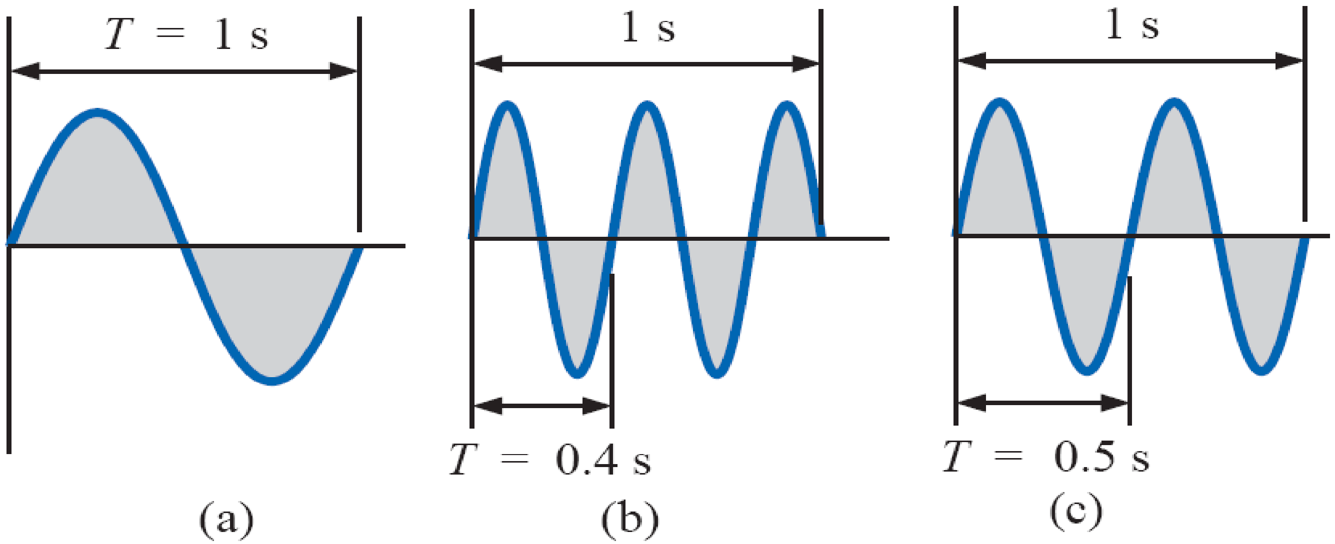
It is the time interval between successive repetitions of a periodic waveform, or the time taken to complete one cycle.

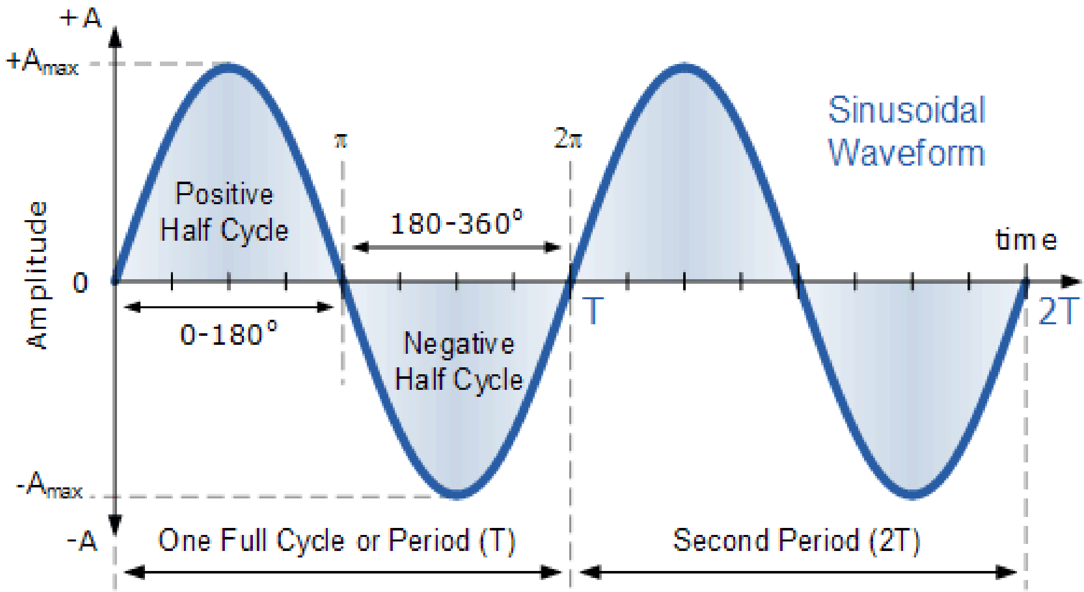
- **Cycle**

It is the portion of a waveform contained in one period of time.

- **Frequency (f)**

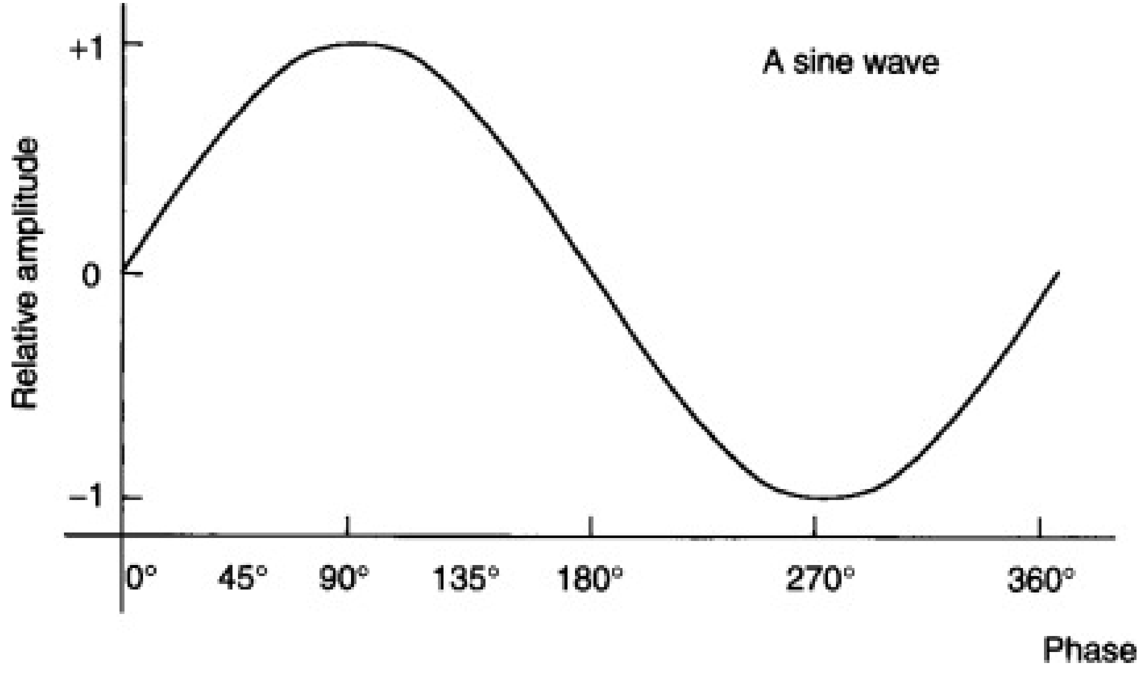
It is the number of cycles that occur in one second. Its unit is called Hertz (Hz=cycles/second).





Sinusoidal wave

- A sine wave or sinusoidal wave is the most natural representation of how many things in nature change state.
- A sine wave shows how the amplitude of a variable changes with time.
- The number of times the sine wave goes through a complete cycle in the space of 1 second is called the frequency.
- Indeed the unit used to be cycles per second, but now the unit of measurement is hertz (Hz).



Sine Wave: Cycle, Frequency and Period

The period and frequency are reciprocals of each other.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Thus, if you know one, you can easily find the other.
(The $\boxed{1/x}$ key on your calculator is handy for converting between *f* and *T*.)

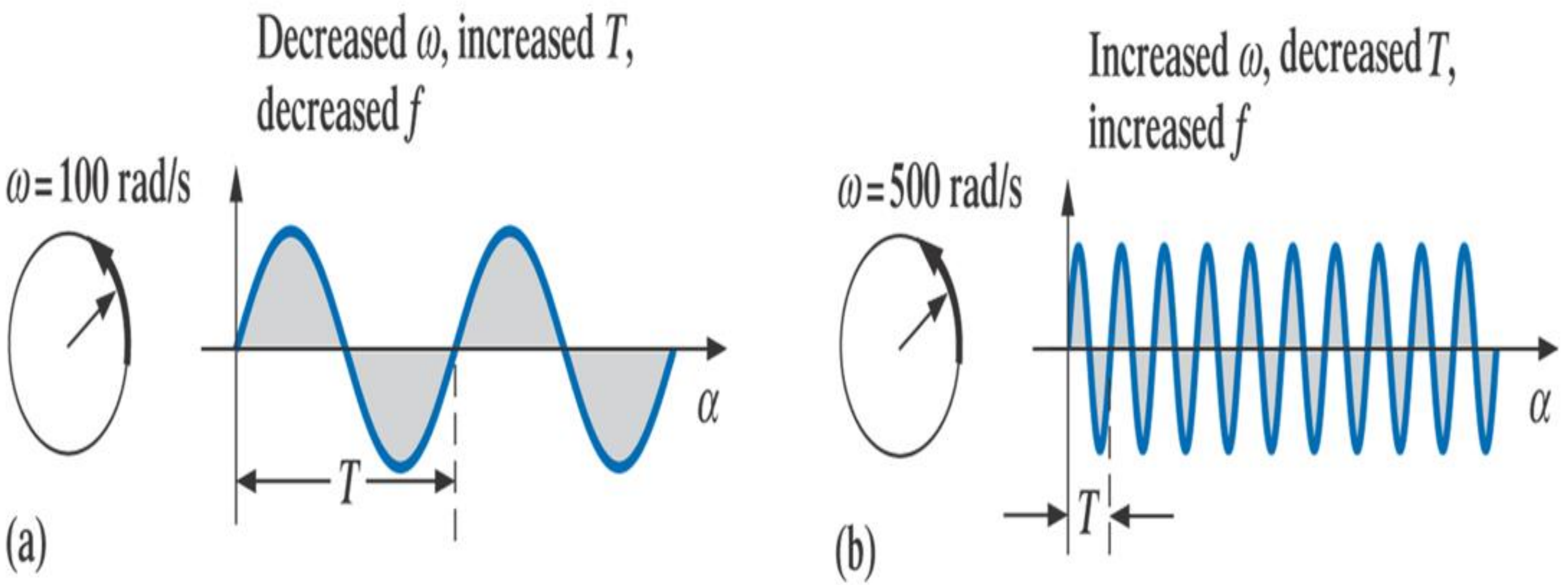
Example

If the period is 50 ms, the frequency is 0.02 MHz = 20 kHz.

Sine Wave: Cycle, Frequency and Period

This equation states that the higher the frequency of the generated sinusoidal waveform, the higher must be the angular velocity.

$$\omega = \frac{2\pi}{T} = 2\pi f \ \ rad/s$$



Demonstrating the effect of ω on the frequency and period.

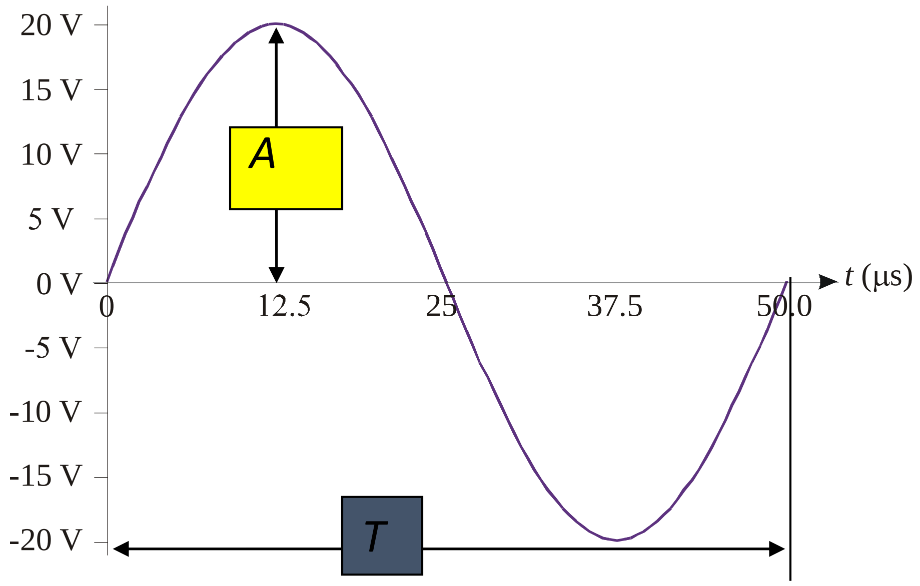
Sine Wave: Cycle, Frequency and Period

- ✓ Sine waves are characterized by the amplitude and period.
- ✓ The **amplitude** is the maximum value of a sinusoidal wave.
- ✓ The **period** is the time interval for one complete cycle.

Example

The amplitude (A) of this sine wave is 20 V

The period is 50.0 μs



Angular measurement

Because there are 2π radians in one complete revolution and 360° in a revolution, the conversion between radians and degrees is easy to write.

To find the number of radians, given the number of degrees:

$$\boxed{\text{rad} = \frac{2\pi\ \text{rad}}{360^\circ} \times \text{degrees}}$$

To find the number of degrees, given the radians:

$$\boxed{\text{deg} = \frac{360^\circ}{2\pi\ \text{rad}} \times \text{rad}}$$

Phase shift

- ✓ The phase of a sine wave is an angular measurement that specifies the position of a sine wave relative to a reference (which is usually zero).

- ✓ To show that a sine wave is shifted to the left or right of this reference, a term is added or subtract to the wave equation.

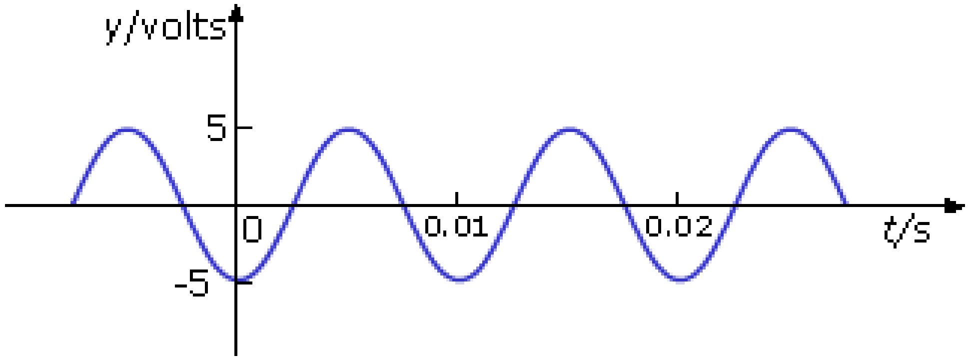
$$\boxed{y = A_m \sin\left(2\pi f t \pm \phi\right)}$$

where

ϕ = Phase shift

Sine wave: Equation

- $y = A_m \sin(2\pi f t + \varphi)$
  - y represents signal value at time t
  - A_m represents the amplitude
  - f is the frequency
  - φ is the phase

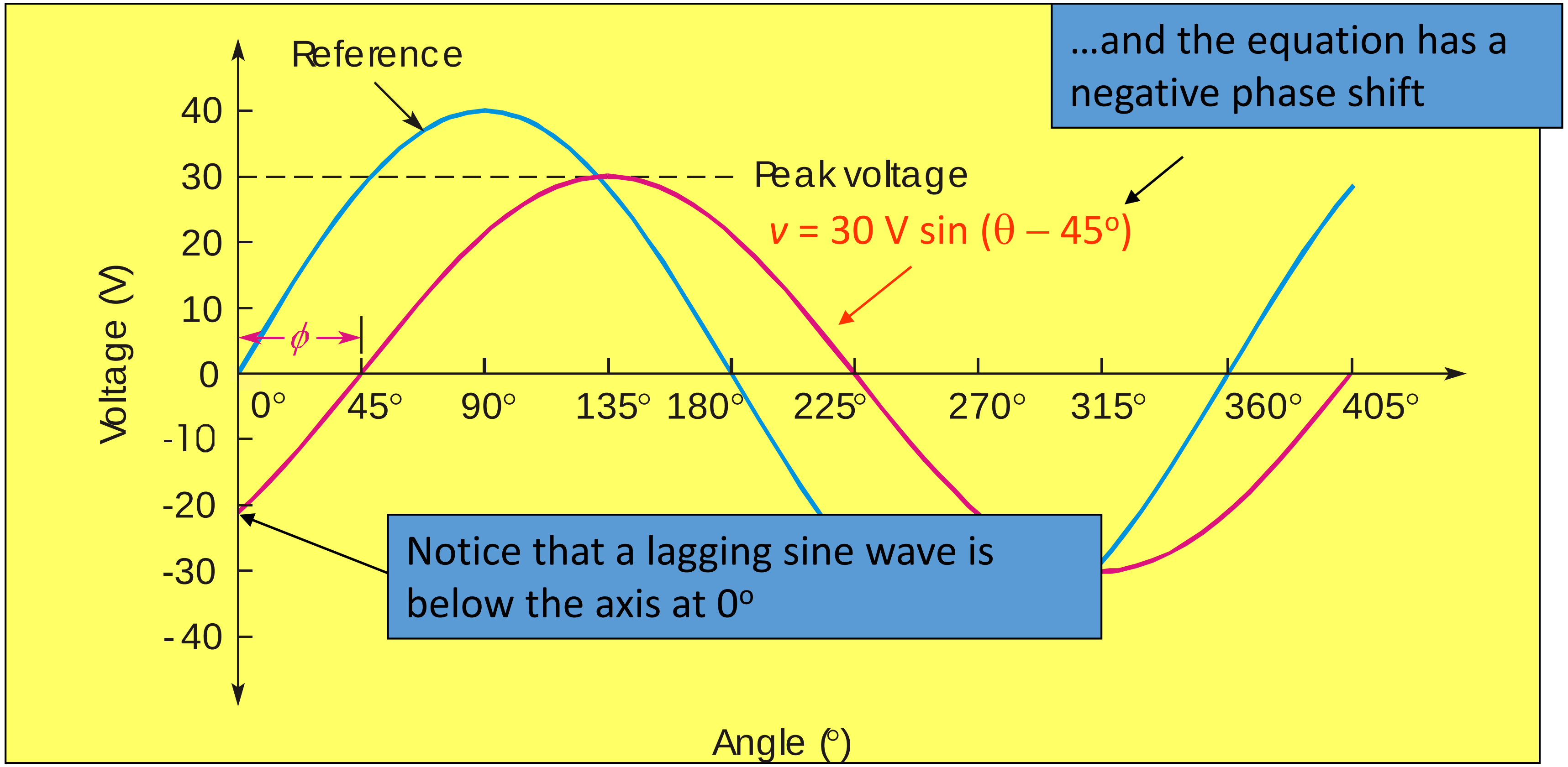


The equation for the sine wave is:
$y = 5 \sin(200\pi t - \pi/2)$ volts

- The term $(2\pi f t + \varphi)$ represents an angle that is growing as time passes.
- This angle is measured in radians rather than degrees.
- For the above sine wave, it is clear that the amplitude A_m has the value 5 volts.
- φ is a quarter of a cycle is 90 degrees, or $\pi/2$ radians.
- Since the sine wave lags behind the reference sine wave, Then we have $\varphi = -\pi/2$ radians.

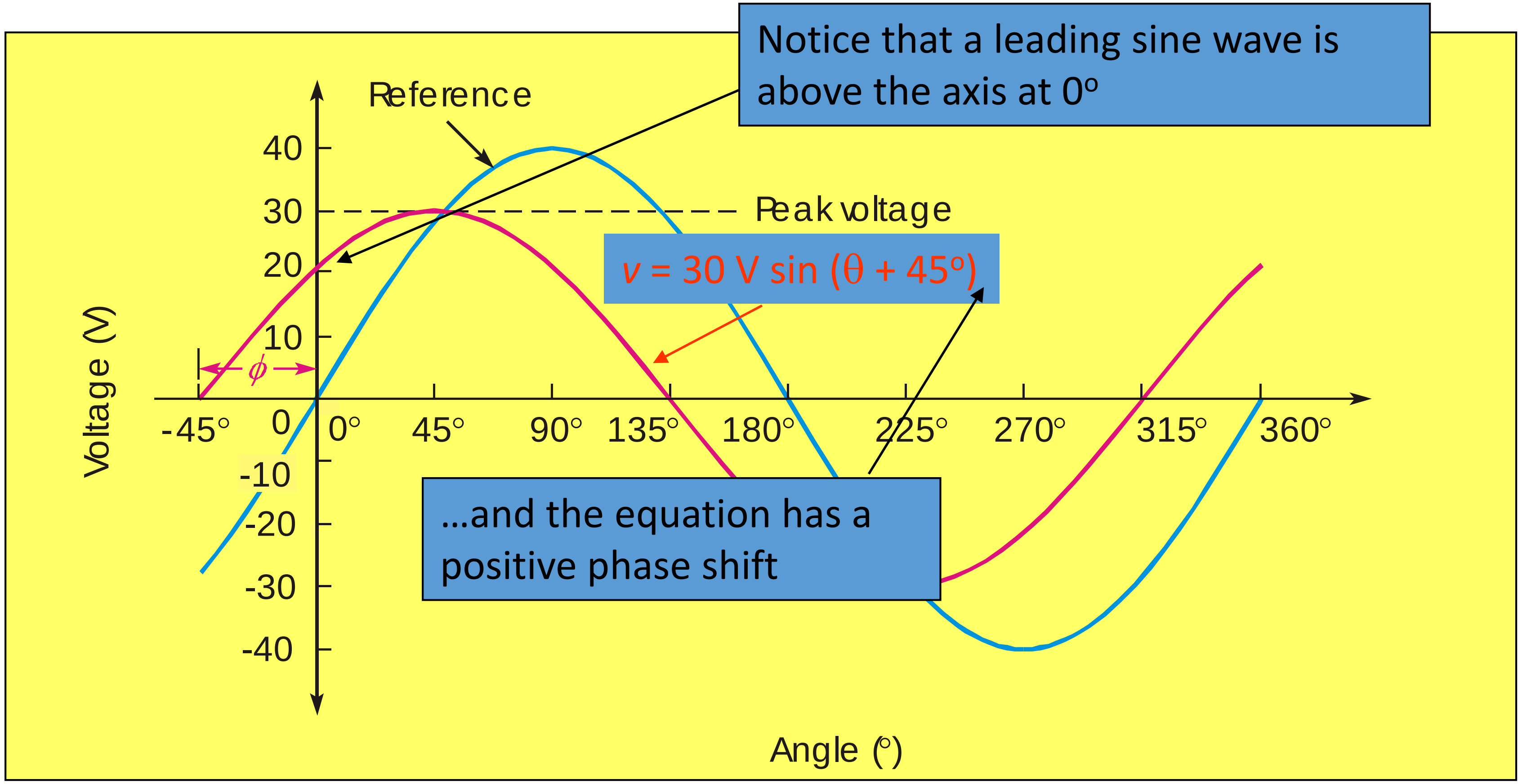
Phase shift

Example of a wave that lags the reference



Phase shift

Example of a wave that leads the reference



Questions

Medical Physics

Lecture_5 : Radiometry and Photometry

Radiometry

- Radiometry is the measurement of the energy of electromagnetic waves (EMW) and it is one of the most important fields of experimental physics, reaching all Natural Sciences.
- A human eye is sensitive only to a fraction of the EM spectrum, ranging approximately from 400 nm to 760 nm.
- Human eye's sensitivity varies with wavelength, growing from 400 nm to 555 nm, where it reaches a maximum, <u>then</u> decreasing up to 760 nm, where it reaches a value of zero.

Radiometry & Photometry

- That is the reason of the existence of two different system of units.
- In one hand the radiometric units or energetic units, characterizing the energy of a light beam.
- On the other hand, the photometric units, characterizing the action of EMW upon a human eye.
- Both systems may have misinterpreted of the definition of their magnitudes, without a precise relation among related units of both systems.

What is Radiometry?

- Radiometry <u>is the</u> science of measuring the light in any portion of the electromagnetic spectrum.
- In practice, the radiometry <u>is usually limited to</u> the measurement of infrared, visible and ultraviolet light using optical instruments.
- Irradiance <u>is the</u> intensity of light, and it is measured in watts per square meter (**W/m^2**).

What is Photometry?

- Photometry is the science of measuring the visible light in units that are weighted according to the sensitivity of the human eye.
- Photometry is a quantitative science based on a statistical model of the human visual response to light, *which is* our perception of light under carefully controlled conditions.
- The photometric equivalent to irradiance is called illuminance.
- Illuminance is measured in Lumens per square meter (**Lm/m^2** = **Lux**).

Radiometry vs. Photometry

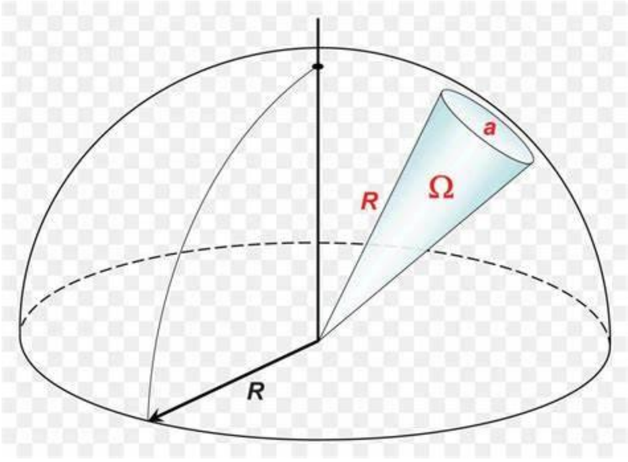
- Radiometry studies the absolute power of the electromagnetic radiation.
- Photometry considers the eye's response characteristic, weighting the radiation of light by the luminosity function.
- Then, the photometric quantities and radiometric quantities use different units of measurement.
- For example, a light bulb emits a certain radiant flux (measured in watts), **but only** a part of the total emitted radiant power – luminous flux (measured in lumens) – is visible to humans.

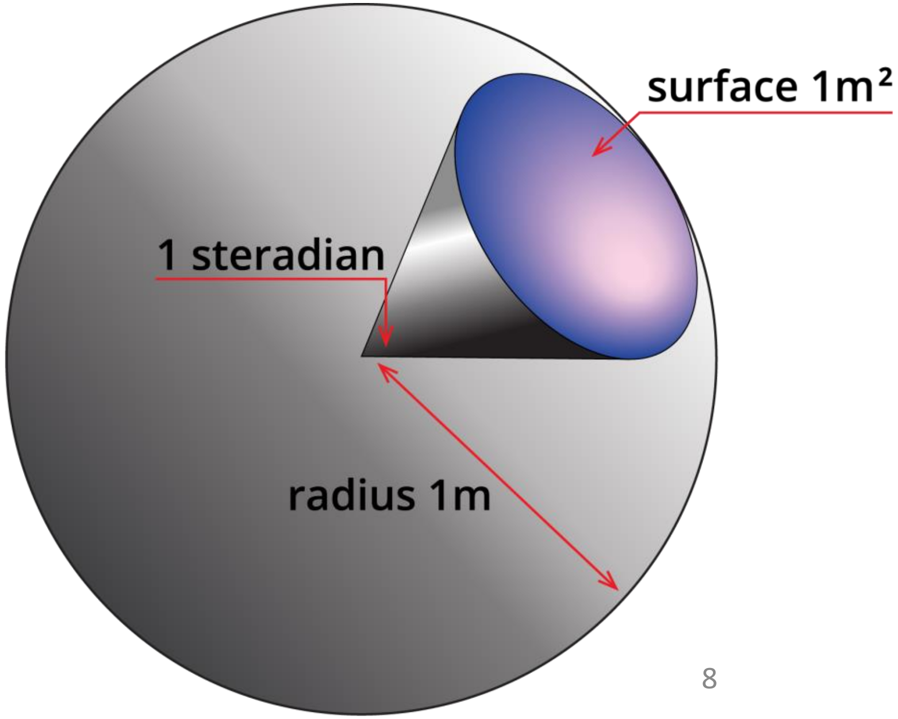
Luminous Flux (Φ)[lm]

- Luminous flux describes the total radiance emitted by a light source as perceived by a human visual system.
- Since the human visual system is much more sensitive in **green-to-yellow** than in its **red** parts of the spectrum, the same absolute power of the radiation would provoke a much stronger sensation of green than that of the red light.
- The luminous flux (Φ), also referred to as luminous power, is measured in lumens (**Lm**).
- The photometric quantities are related to the luminous flux.

Solid Angle **Ω**

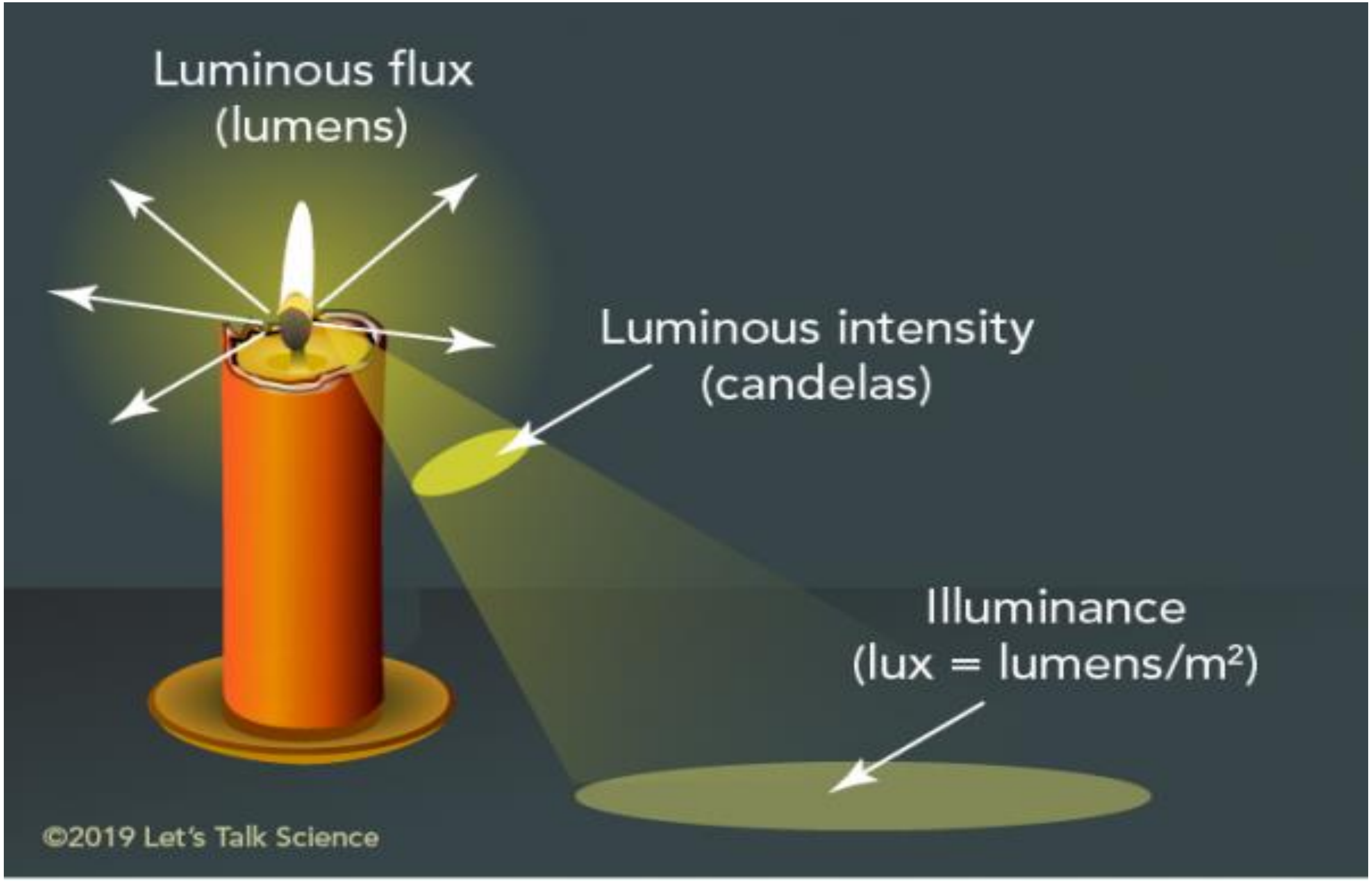
- solid angle **Ω**, is a measure of the amount of the field of view from some particular point that a given object covers. That is, it is a measure of how large the object appears to an observer looking from that point.
- solid angle **Ω**, measured in steradian (**sr**).





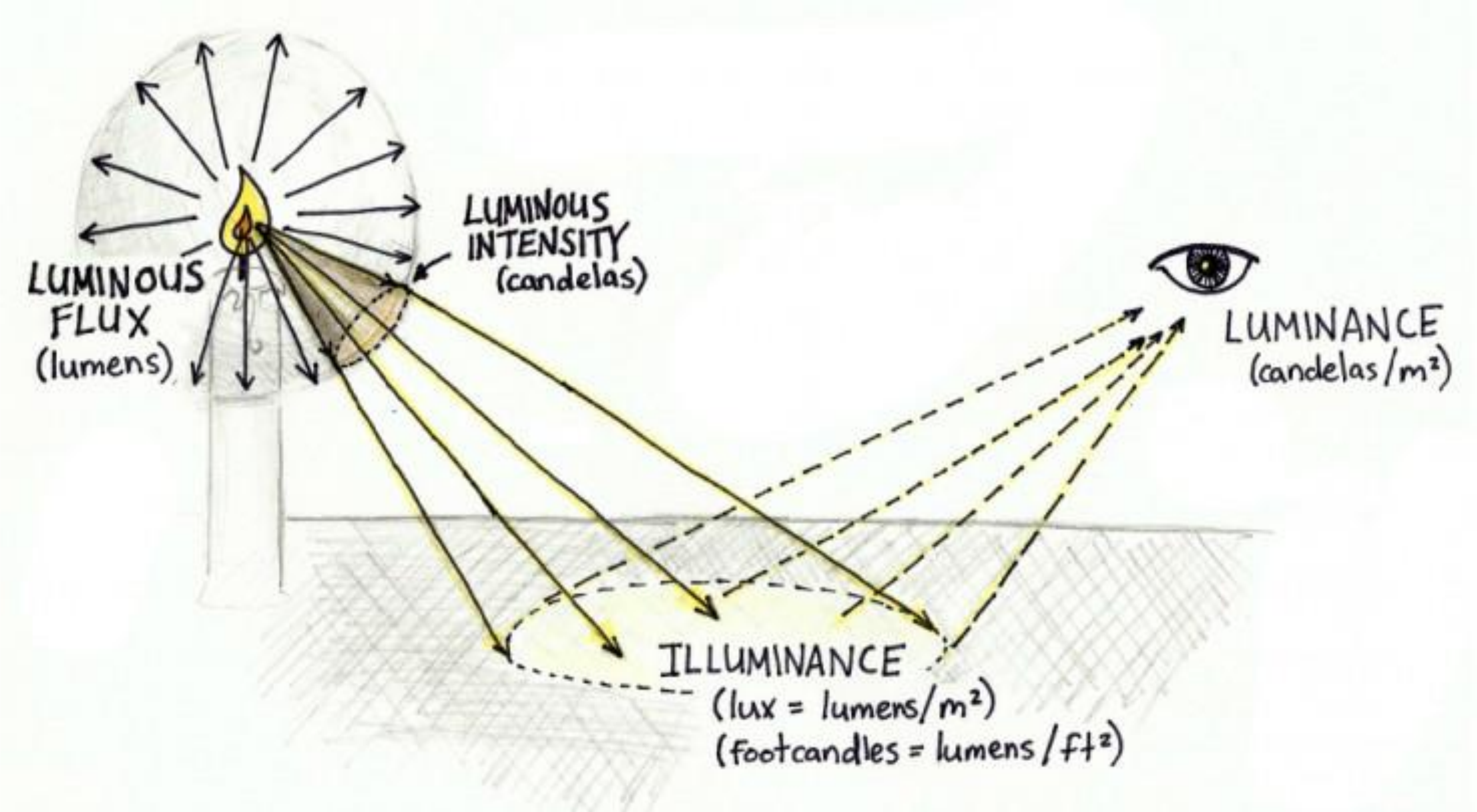
Luminous Intensity (I) [cd]

- In general, light sources do not emit light homogeneously in all directions.
- The luminous intensity (I) describes the luminous flux emitted within a certain angle in a three-dimensional space (i.e., solid angle **Ω**, measured in steradians (**sr**)).
- luminous intensity (i) unit is *candela* (**cd**) can be substituted by lumens per steradian (**lm/sr**).


Luminous flux
(lumens)
Luminous intensity
(candelas)
Illuminance
(lux = lumens/m²)
©2019 Let's Talk Science

Luminance (L) [cd/m2]

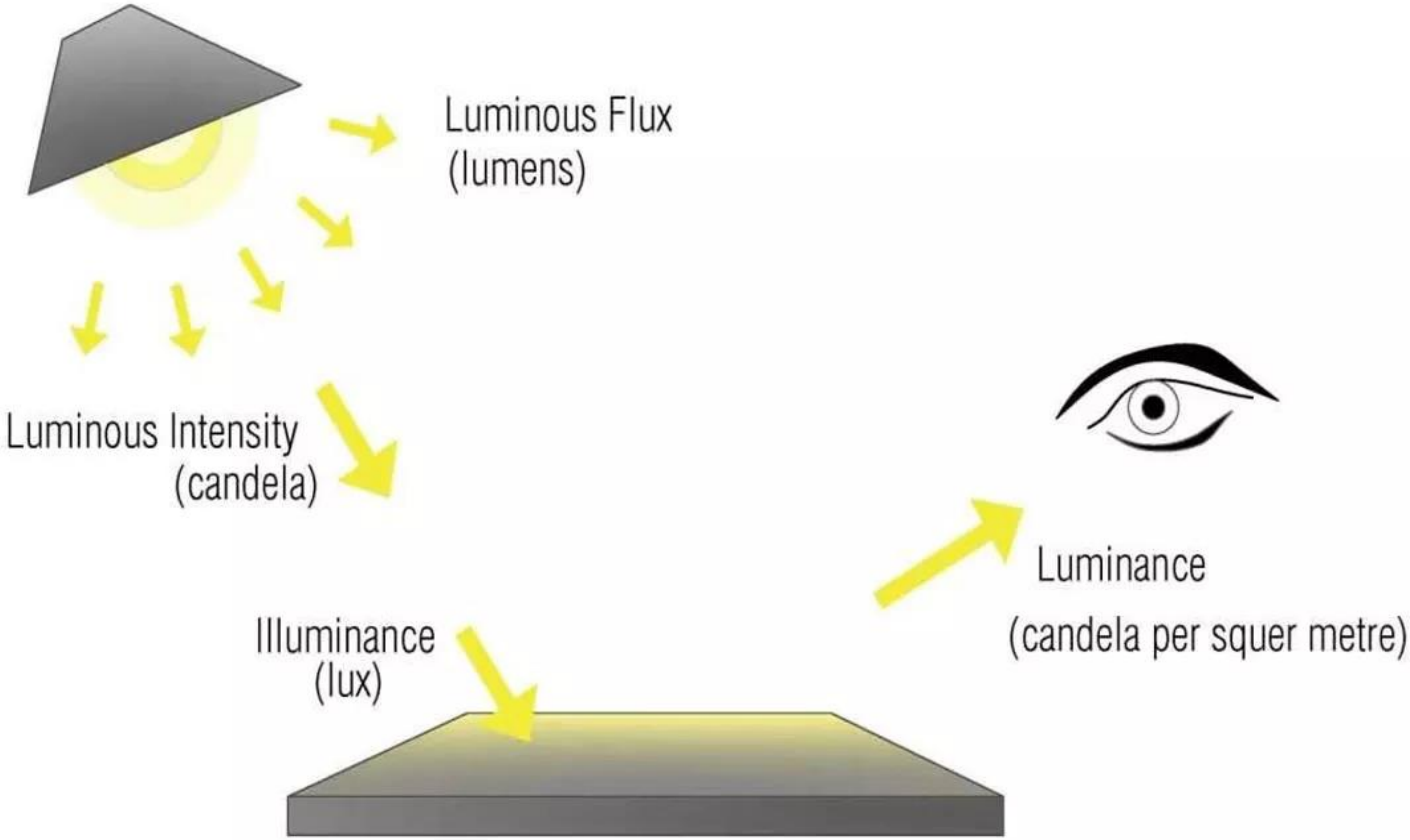
- Luminance (L) is the describe of the amount of luminous intensity that passes through (or is emitted by) a certain area from a certain angle.
- Taking the solid angle of a humans eye as a measure of spatial distribution of light, luminance (L) describes how bright an emitting or reflecting area would appear.
- The SI luminance unit **is** candela per square meters (**cd/m^2**).
- The non-SI luminance unit **is** "nit“, where (1 **nit** = 1 **cd/m^2**).



LUMINOUS FLUX
(lumens)
LUMINOUS INTENSITY
(candelas)
LUMINANCE
(candelas/m²)
ILLUMINANCE
(lux = lumens/m²)
(footcandles = lumens/ft²)

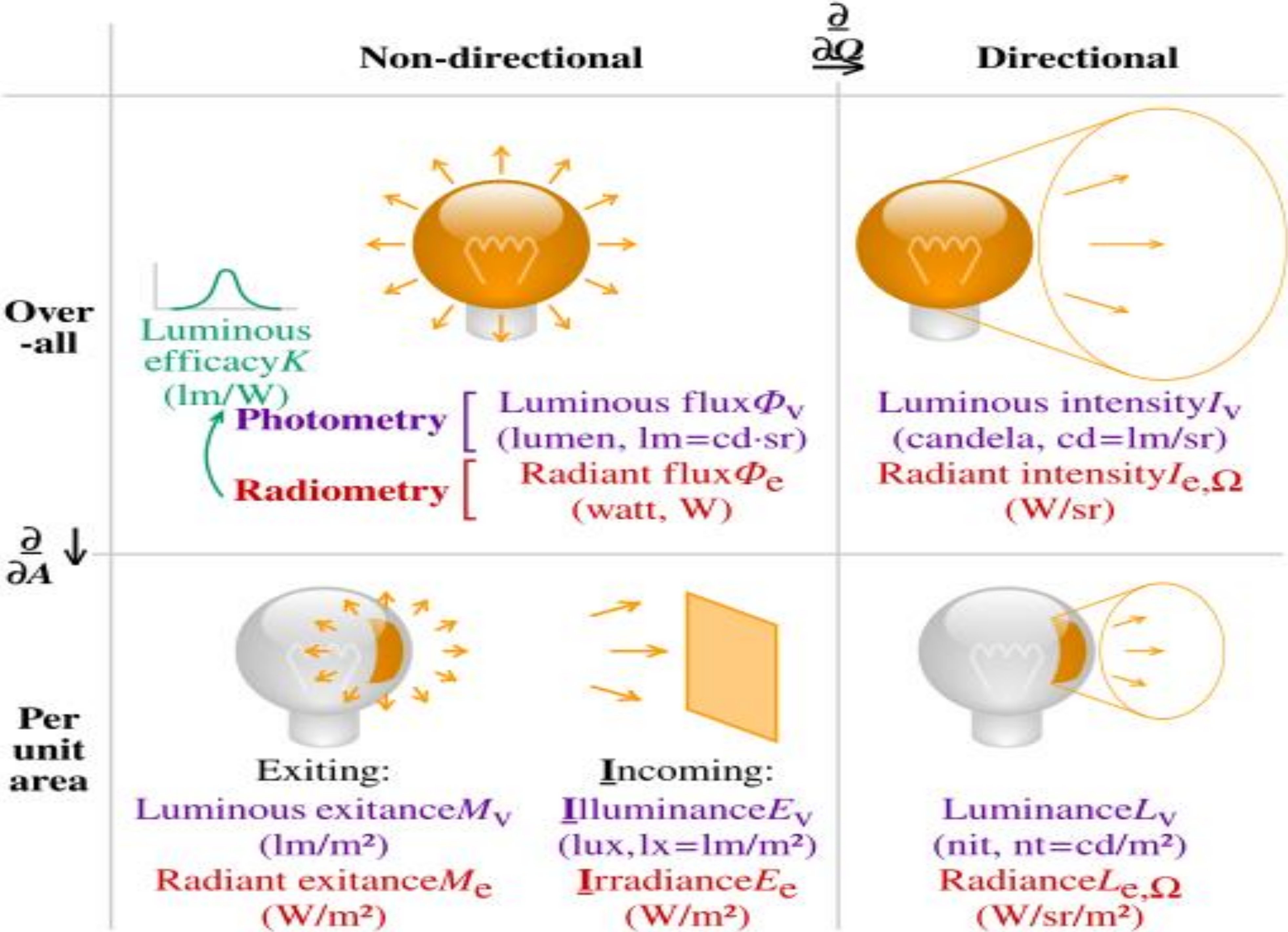
illuminance and Luminous Emittance (E) [lx]

- Illuminance describes the quantity of a total light energy weighted by the eye's sensitivity function incident on a certain area.
- Luminous emittance (E) is a measure of the total luminous power emitted from a surface with a certain area.
- They both describe the **total luminous flux per unit area**.
- Illuminance (E) is measured by lumens per square meters **or** Lux.
- Illuminance is also given in foot-candles (f.cd), that is lumen per square foot (**1 f.cd = 10.76 Lux**).


Luminous Flux
(lumens)
Luminous Intensity
(candela)
Illuminance
(lux)
Luminance
(candela per squer metre)

Luminous Exposure

- Luminous Exposure describes the accumulated luminous intensity applied to a certain area (e.g. camera sensor) within a certain time period.
- In other words, Luminous Exposure **is the** illuminance per unit time.
- The unit of Luminous Exposure **is** (Lux . second) → (Lux·s).

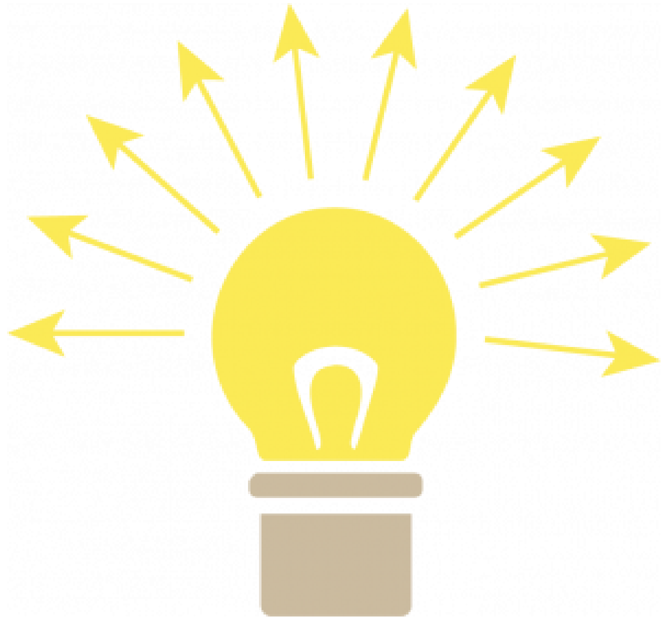

Non-directional
$\frac{\partial}{\partial \Omega}$
Directional
Over-all
Luminous efficacy K (lm/W)
Photometry
Radiometry
Luminous flux Φ_v (lumen, lm=cd·sr)
Radiant flux Φ_e (watt, W)
Luminous intensity I_v (candela, cd=lm/sr)
Radiant intensity $I_{e,\Omega}$ (W/sr)
$\frac{\partial}{\partial A}$
Per unit area
Exiting:
Luminous exitance M_v (lm/m²)
Radiant exitance M_e (W/m²)
Incoming:
Illuminance E_v (lux, lx=lm/m²)
Irradiance E_e (W/m²)
Luminance L_v (nit, nt=cd/m²)
Radiance $L_{e,\Omega}$ (W/sr/m²)

Radiometric Quantifies - Radiant power or radiant flux Φe

- Radiant power (Φ_e) is defined as the total power of radiation emitted by a light source transmitted through a surface.
- Radiant power is measured in watts (**W**).
- The definitions of all other radiometric quantities are based on radiant power.
- If a light source emits uniformly in all directions, it is called an isotropic light source.

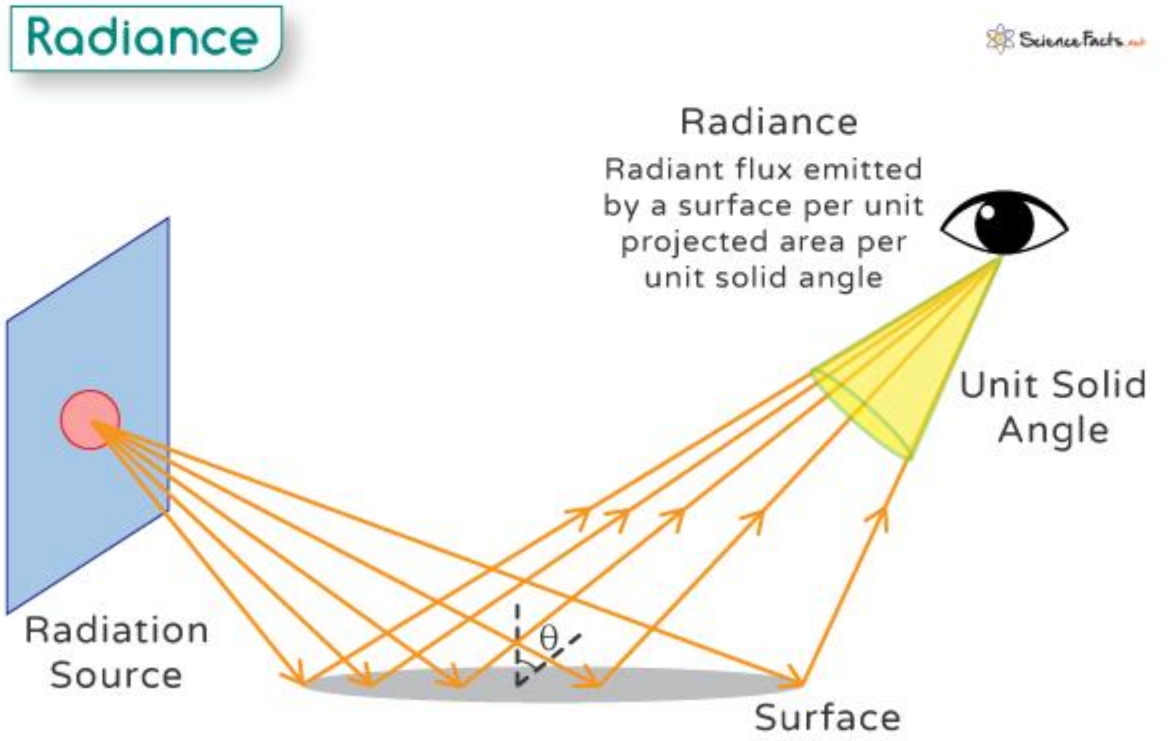
Radiometric Quantifies-Radiant power or radiant flux (Φe)

- Radiant power characterizes the output of a source of electromagnetic radiation only by a single number.
- Radiant power **and does not** contain any information on the spectral distribution **or** the directional distribution of the light source output.



Radiance (L_e)

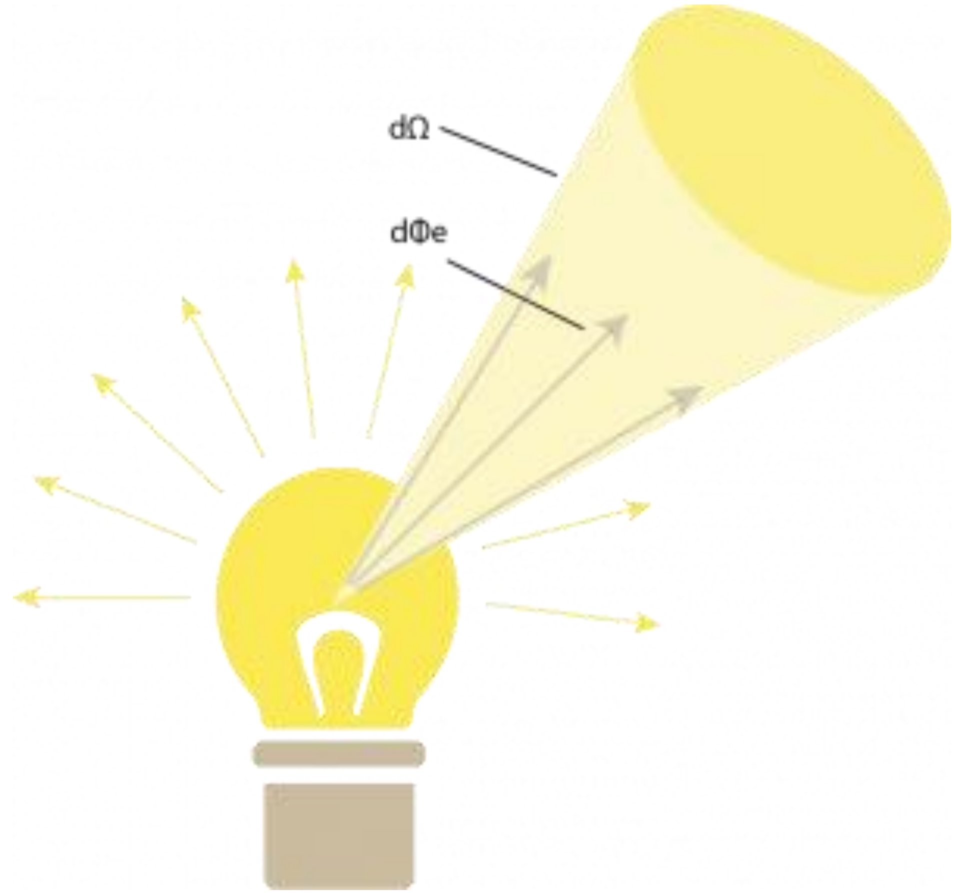
❖ The radiance (**L_e**) is the intensity of optical radiation emitted or reflected from a certain location on an emitting or reflecting surface in a particular direction.



Radiance (L_e)

- Mathematically, it is the (differential) radiant power **$d\Phi_e$** emitted by a (differential) surface element **dA** in the direction of the solid angle element **dΩ** is given by

$$d\Phi_e = L_e \times cos(\vartheta) \times dA \times d\Omega$$

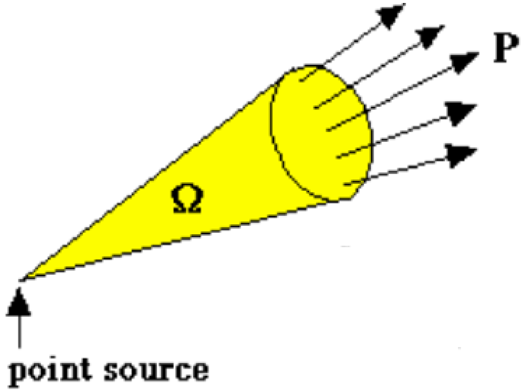


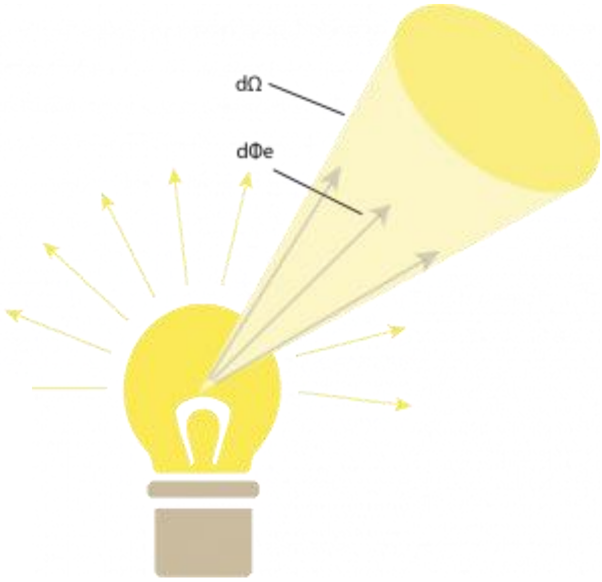
Radiant intensity (I_e)

- **Radiant intensity (I_e)** describes the radiant power of a source emitted in a certain direction. The source's (differential) radiant power (**$d\Phi_e$**) emitted in the direction of the (differential) solid angle element (**$d\Omega$**) is given by $d\Phi_e = I_e\, d\Omega$

- The radiant intensity depends on spatial direction.

- The **unit** of radiant intensity is **W/sr**

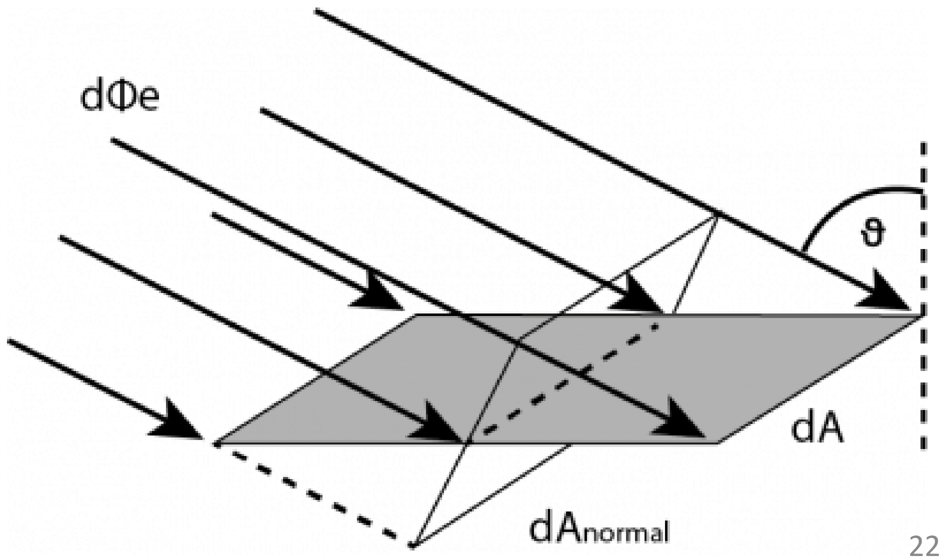




Irradiance (Ee)

- The irradiance (E_e) is the amount of radiant power impinging upon a surface per unit area.
- The (differential) radiant power $d\Phi_e$ upon the (differential) surface element **dA** is given by

$$d\Phi_e = E_e \times dA$$



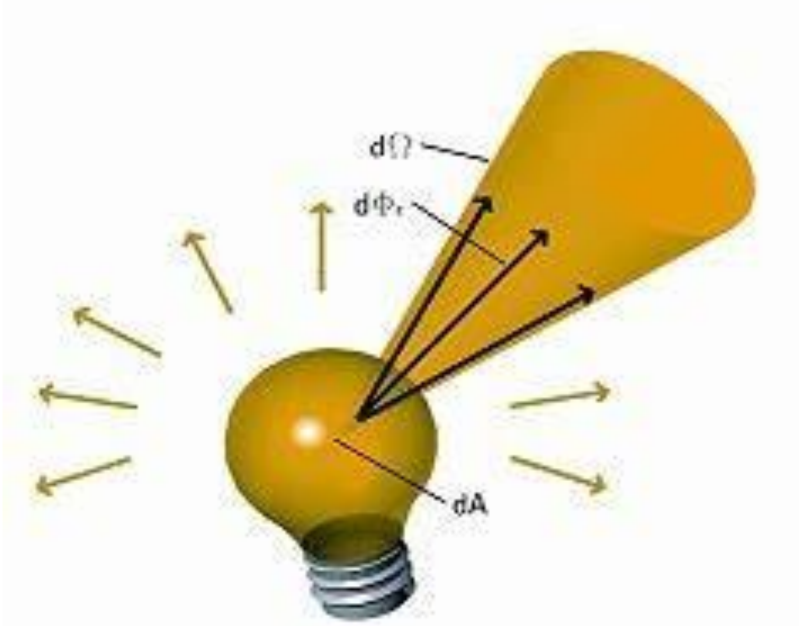
- The unit of irradiance is W/m^2.

Radiant exitance (Me)

- **Radiant exitance** (**M_e**) quantifies the radiant power that is emitted or reflected from a certain location on a surface per area.

- The (differential) radiant power **$d\Phi_e$** emitted or reflected by the surface element **dA** is given by

$$d\Phi_e = Me \times dA$$



The human visual system

- The human visual system responds to the light in the electromagnetic spectrum with wavelengths ranging from 380nm to 770nm.
- We see light of different wavelengths as a continuum of colors ranging through the visible spectrum: 650nm is red, 540nm is green, 450 nm is blue, and so on.
- The sensitivity of the human eye to light varies with wavelength.

The human visual system

- For example, a light source with an irradiance of one Watt/m^2 of green light appears much brighter than the same source with an irradiance of one Watt/m^2 of red or blue light.
- In photometry, we do not measure Watts of radiant energy. But, we measure the subjective impression produced by stimulating the human eye-brain visual system with radiant energy.

The human visual system

- The conversion between photometric units which take into account human physiology and radiometric units is given by the following:

$$\textbf{(photometric unit)} = \textbf{(radiometric unit)} \times \textbf{(683)} \times \mathbf{V(\lambda)}$$

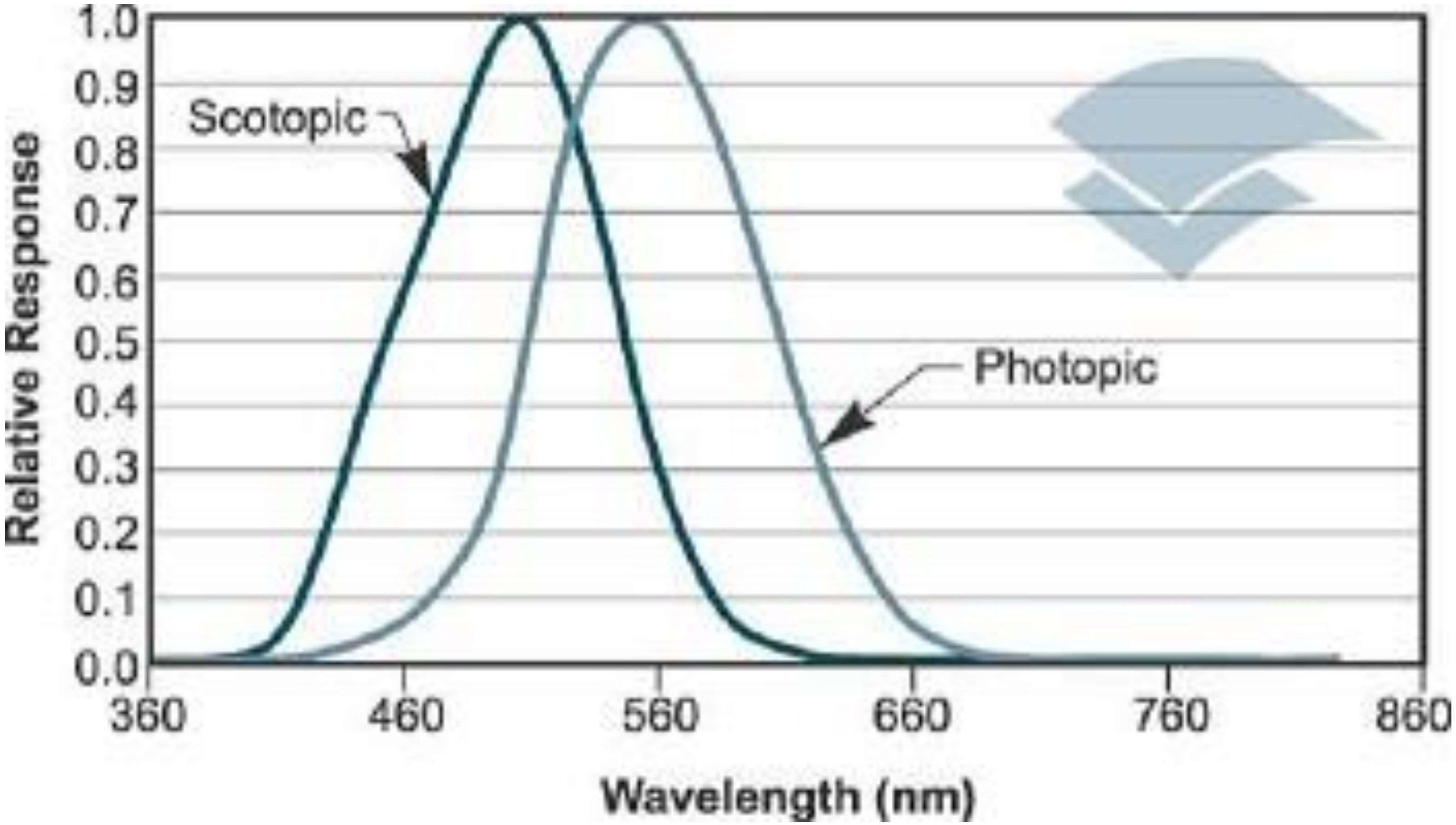
where **$V(\lambda)$** is the 'Photopic Response,' which basically tells us how efficiently the eye picks up certain wavelengths of light.

The human visual system

- The task of human visual system is complicated by the eye's nonlinear response to light.
- The task of human visual system varies not only with wavelength but also with the amount of radiant flux, whether the light is constant or flickering, the spatial complexity of the scene being perceived, the adaptation of the iris and retina, the psychological and physiological state of the observer.

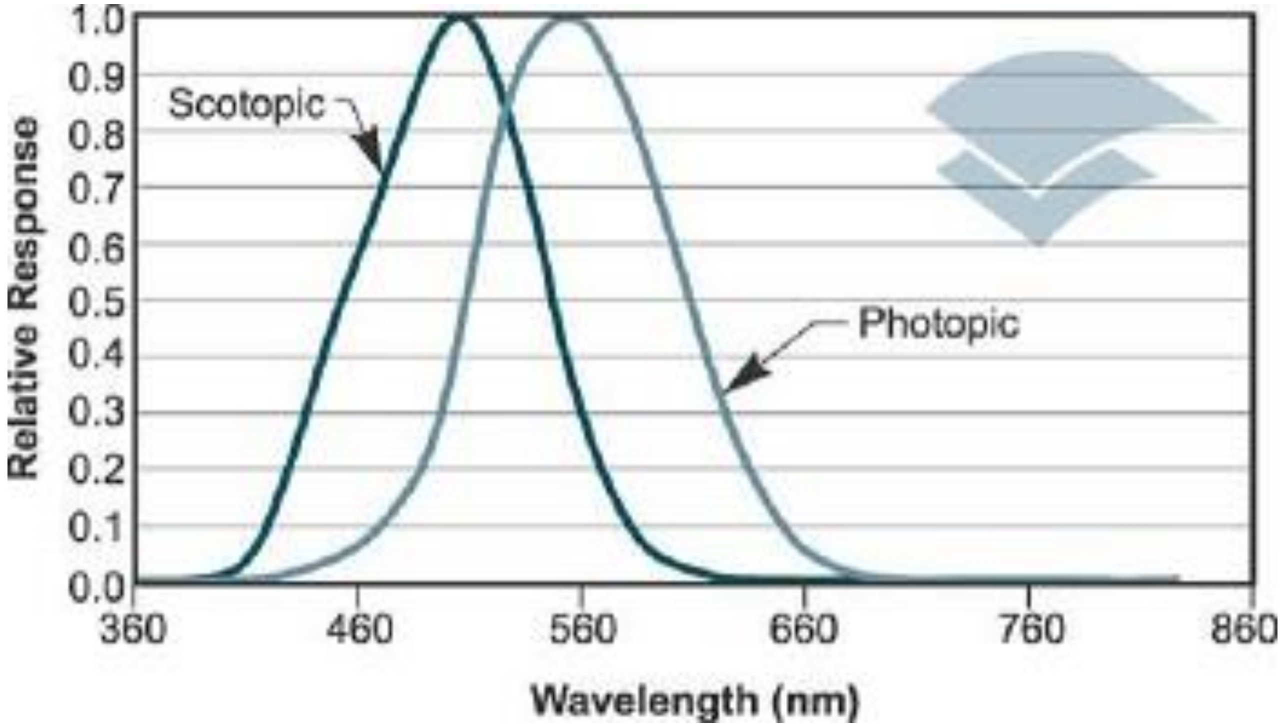
The human visual system

- Taking an average of the measurements results, called Photopic response of the perceived 'average' human observer:



The human visual system

- The curve on the left shows the eyes response to low levels of light and is called the Scotopic response.
- At low level of light, the rods are most active and the human eye is more sensitive to any amount of light that is present, but is less sensitive to the range of color.
- Rods are highly sensitive to light but are comprised of a single photo pigment, which accounts for the loss in ability to discriminate color.



Questions

Medical Physics

Lecture_6 : Reflection and Refraction

LEARNING OBJECTIVES

By the end of the lecture, student will be able to:

- ✓ Understand the meaning of reflection term.
- ✓ Understand the meaning of refraction term.
- ✓ Distinguish the physical explanation of refractive index.
- ✓ Recognize the difference between reflection and refraction.
- ✓ Use the Snell’s Law of Refraction.

Reflection

- Whenever a person looks in a mirror he/she is seeing the reflection of light.

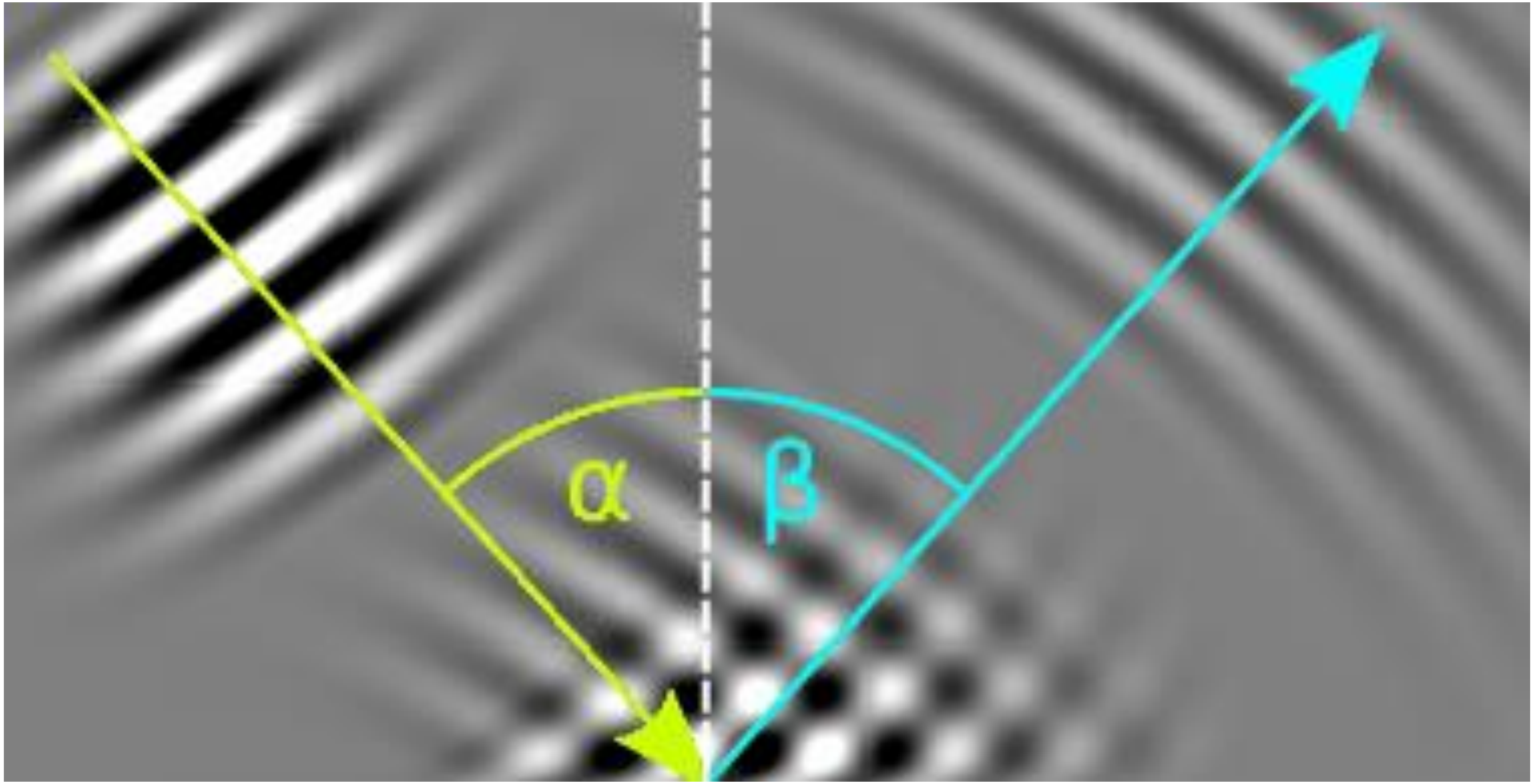
But what is the reflection of light?

Reflection

- The reflection of light <u>is the</u> change of the light direction after encountering a surface **or** other boundary <u>that</u> does not fully absorb the energy of the light.
- <u>Depending on</u> the type of the surface, the light rays will be reflected differently.
- The simplest example is the light reflecting off a mirror.
- In the mirror, the polished surface of the mirror semi perfectly reflects any light incident on it.

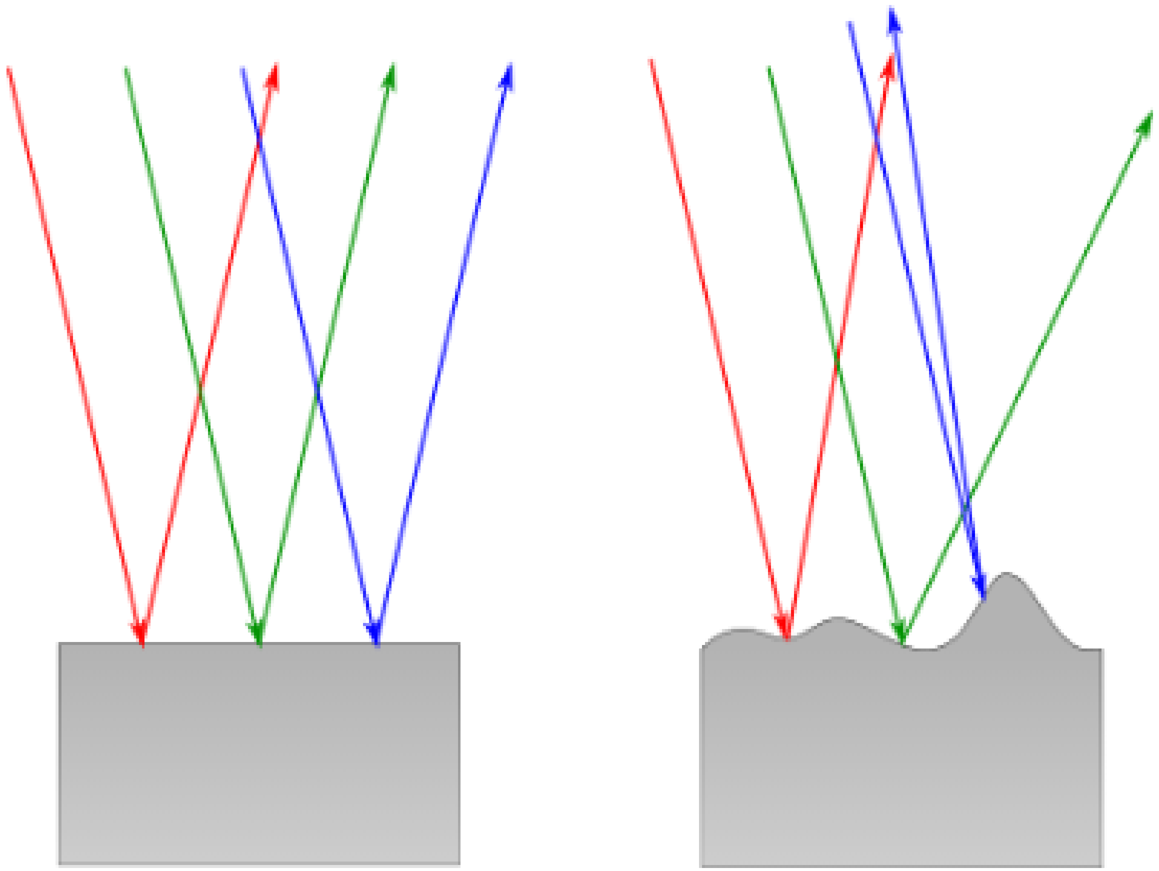
Reflection of Light

- An *incident* light of light travels in a medium.
- When *incident* light encounters a boundary with a second medium, part of the incident ray is reflected back into the first medium.
  - ✓ This means that the *incident* light is directed backward into the first medium.
- For light waves traveling in three-dimensional space, the reflected light can be in direction different from the direction of the *incident* light.


α
β

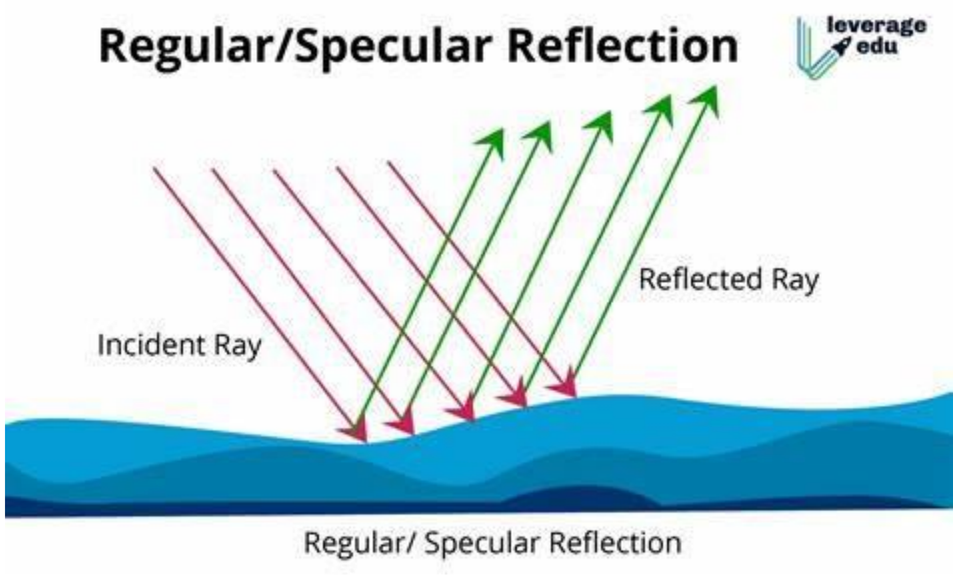
Types of Reflection of Light

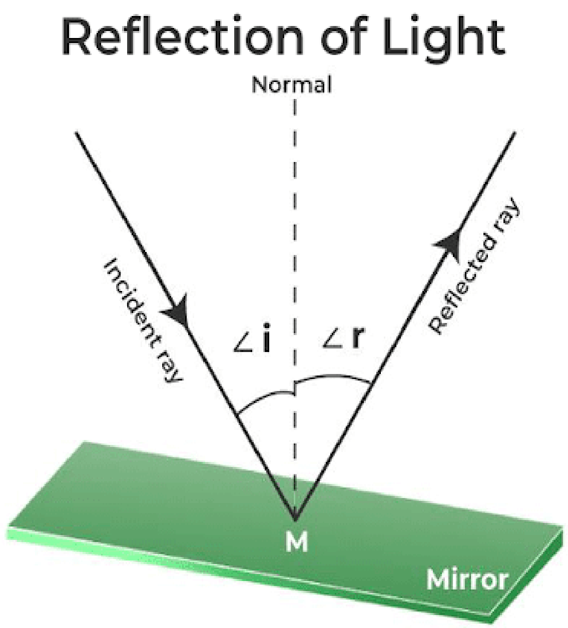
- The reflection of light depends on the surface that it is reflecting from.
- Smooth surfaces, such as mirrors or polished metals, cause specular or regular reflection.
- Rough surfaces, such as gravel or rough water, cause diffuse reflection.



Specular Reflection

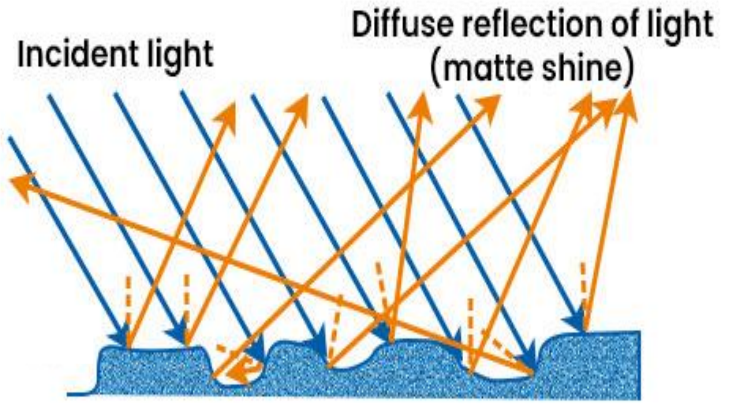
- *Specular reflection* is reflection from a smooth surface.
- In *Specular reflection,* the reflected rays are parallel to each other.
- In *Specular reflection,* all reflections in are assumed to be specular.

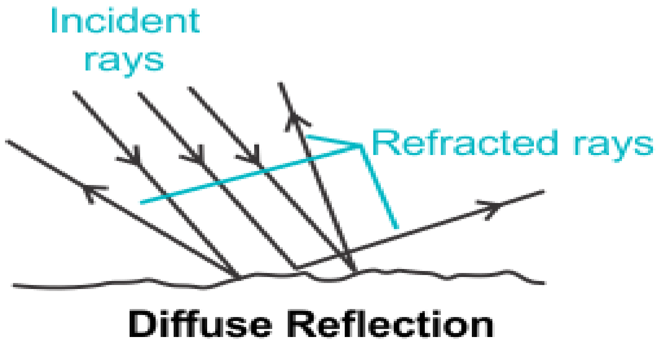


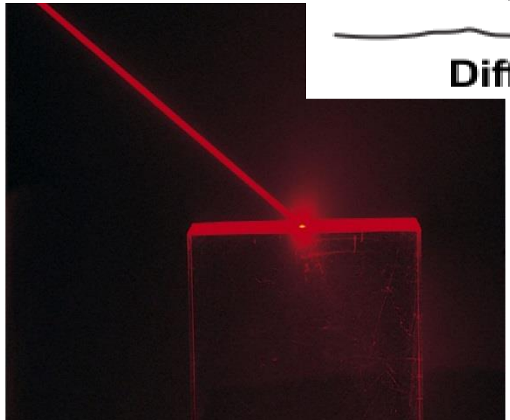


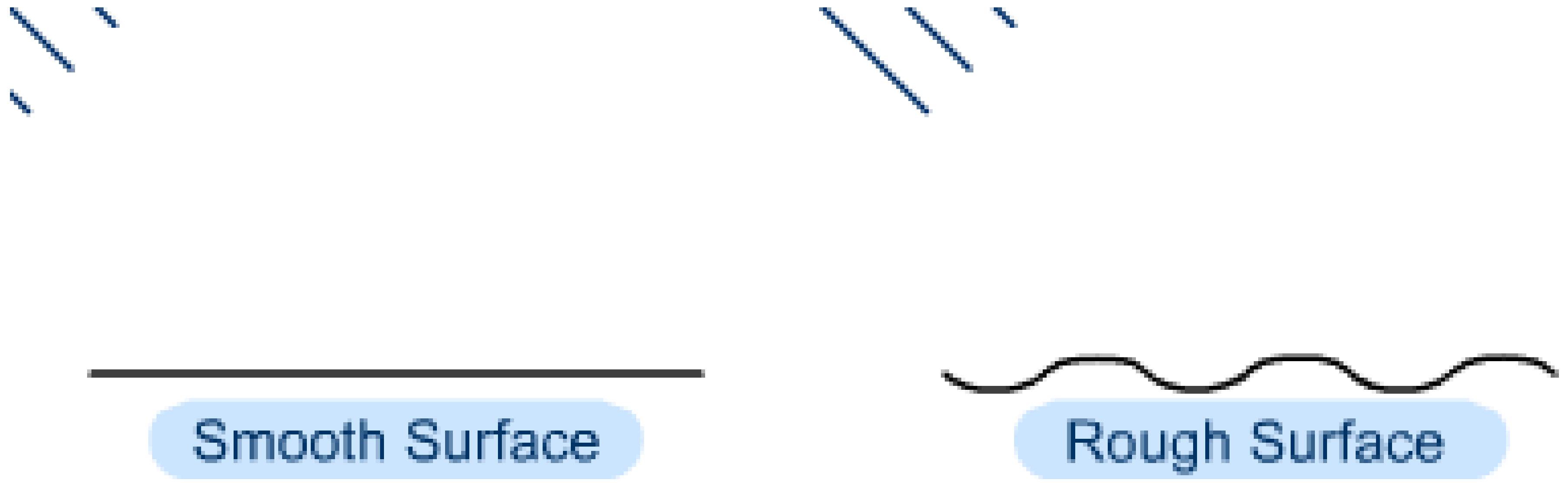
Diffuse Reflection

- *Diffuse reflection* is reflection from a rough surface.
- In *Diffuse reflection* , the reflected rays travel in many directions.
- A surface behaves as diffuser as long as the surface roughness is much larger than the wavelength of the light.



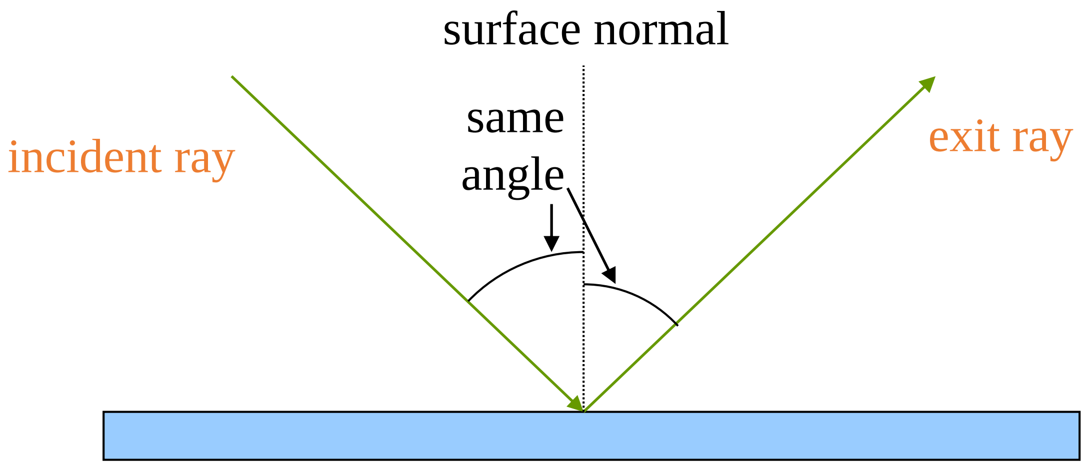





Smooth Surface
Rough Surface

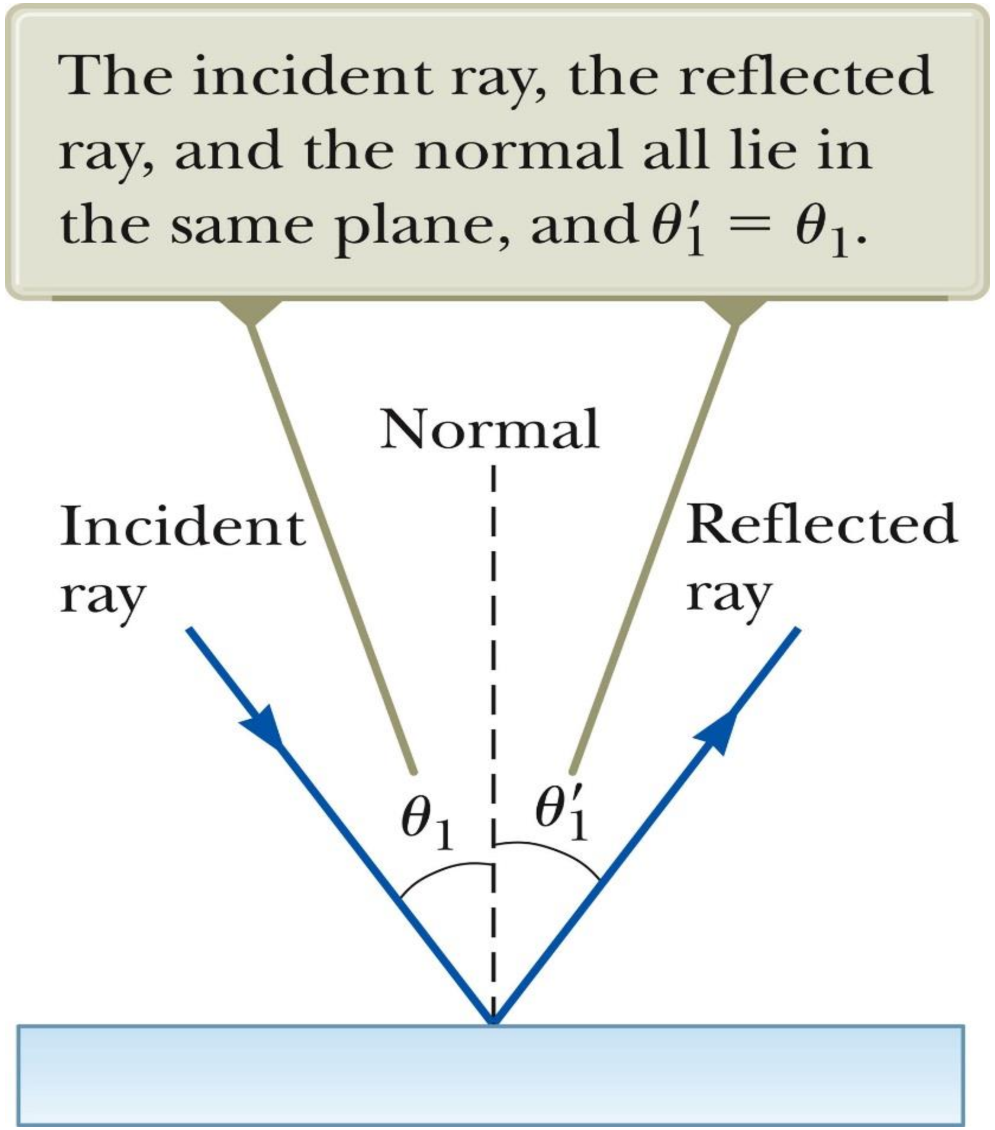
Reflection

- The reflection law describes the path of light as straight-line rays
- Reflection off a flat surface follows a simple rule:
  - ✓ angle in (incidence) equals angle out (reflected)
  - ✓ angles measured from surface "normal" (perpendicular).



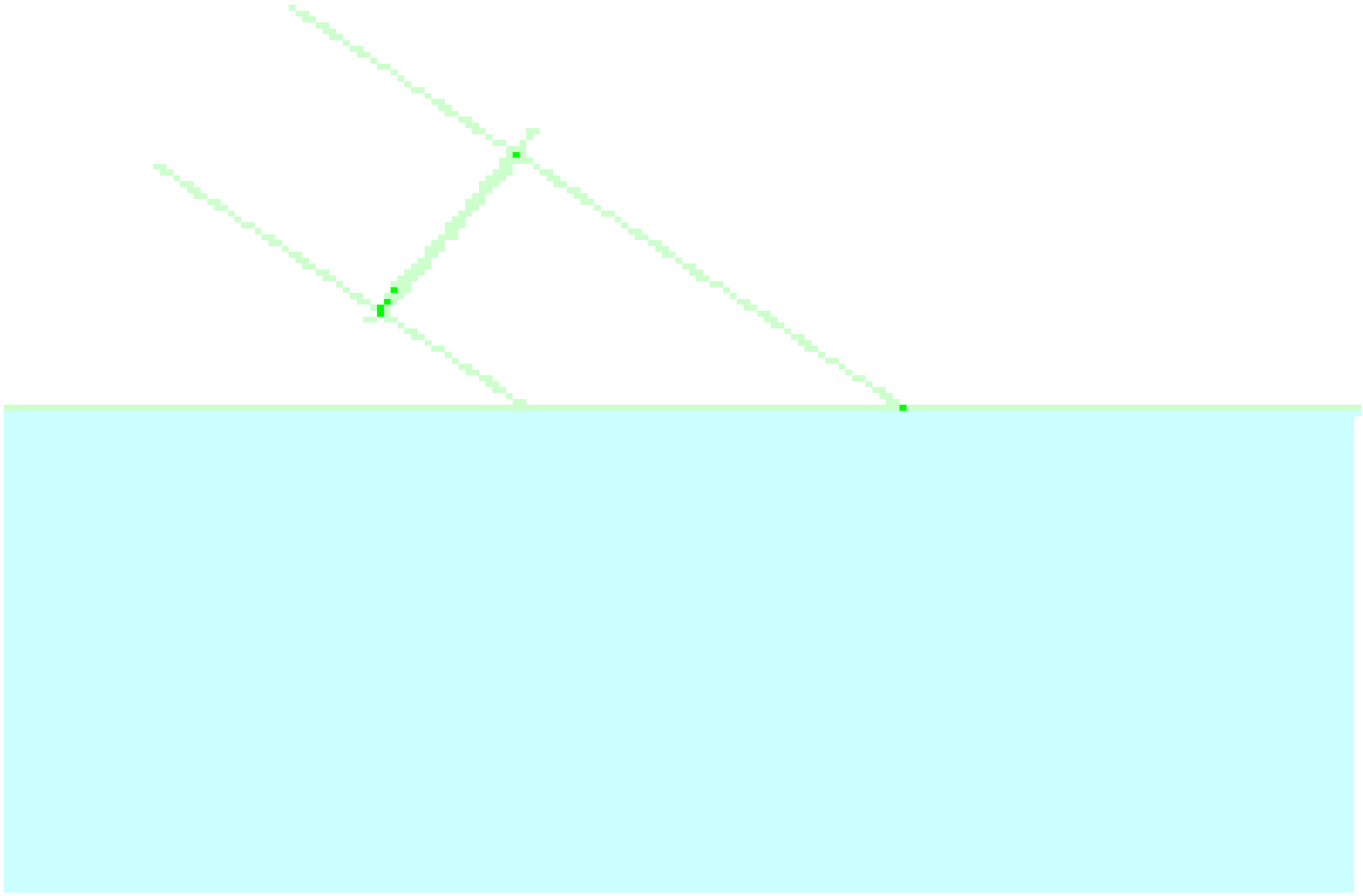
Law of Reflection

- The *normal* is a line perpendicular to the surface.
- It is at the point where the incident ray strikes the surface.
- The incident light makes an angle of θ_1 with the normal.
- The reflected light makes an angle of θ_1' with the normal.



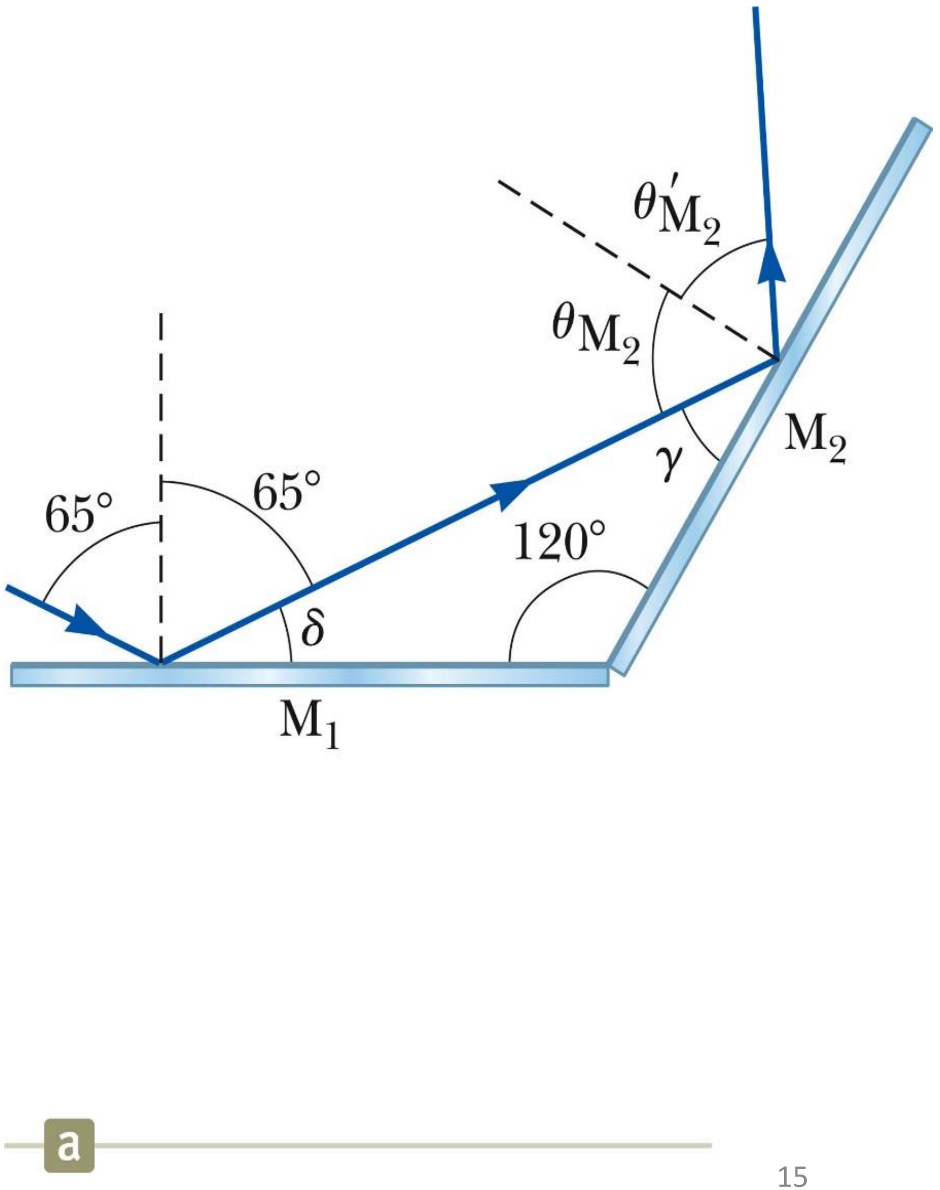
Law of Reflection, cont.

- **The angle of reflection is equal to the angle of incidence, i.e., $\theta_1' = \theta_1$**
  - ✓This relationship is called the Law of Reflection.
- **The incident light, the reflected light and normal are all in the same plane.**
- Notation note:
  - ✓The subscript **1** refers to parameters for the light in the first medium.
  - ✓The subscript **2** will be associated with the new medium.



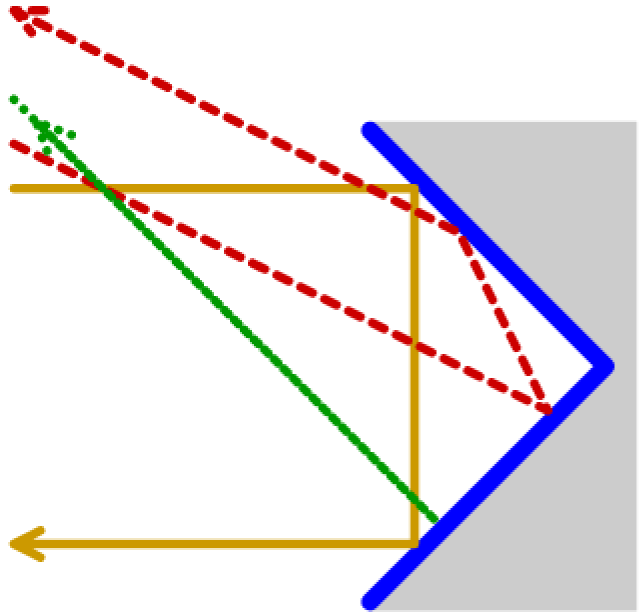
Multiple Reflections

- The incident light strikes the first mirror.
- The reflected light is directed toward the second mirror.
- There is a second reflection from the second mirror.
- Apply the Law of Reflection and some geometry **to determine information about the rays.**

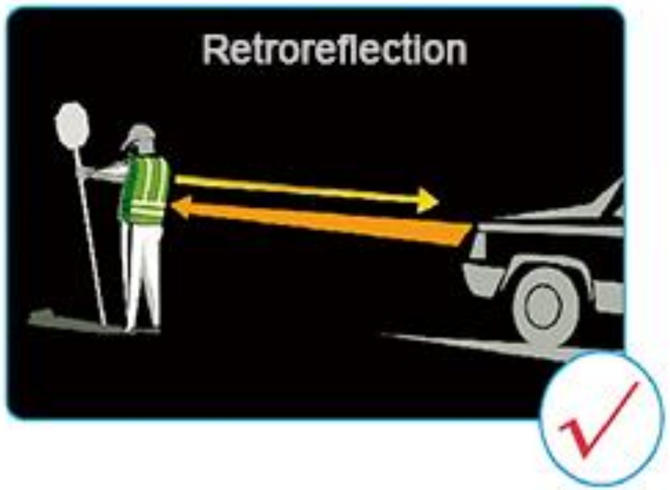


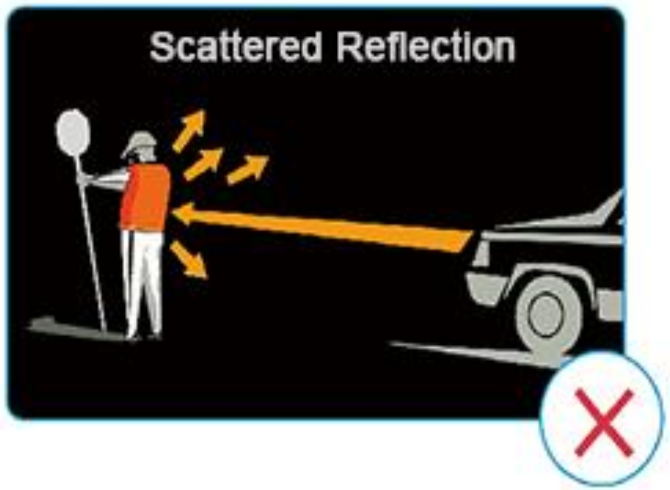
Retroreflection

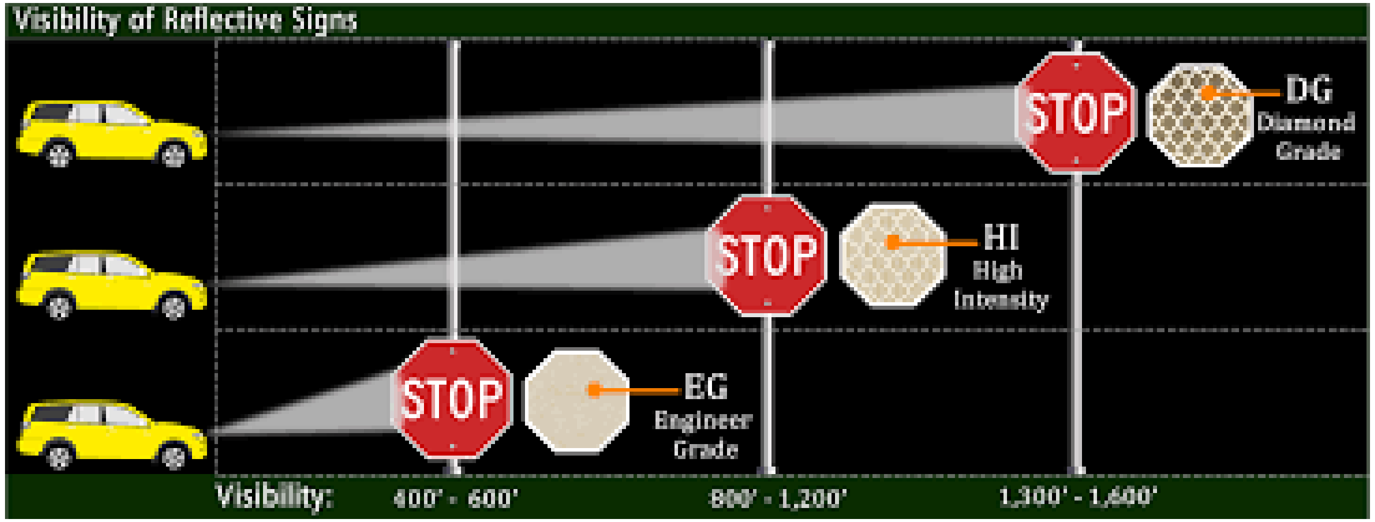
- Assume that the angle between two mirrors is 90^o.
- The reflected beam returns to the source parallel to its original path.
- This phenomenon is called *retroreflection.*
- Applications include:
  - ✓ Measuring the distance to the Moon
  - ✓ Automobile taillights
  - ✓ Traffic signs

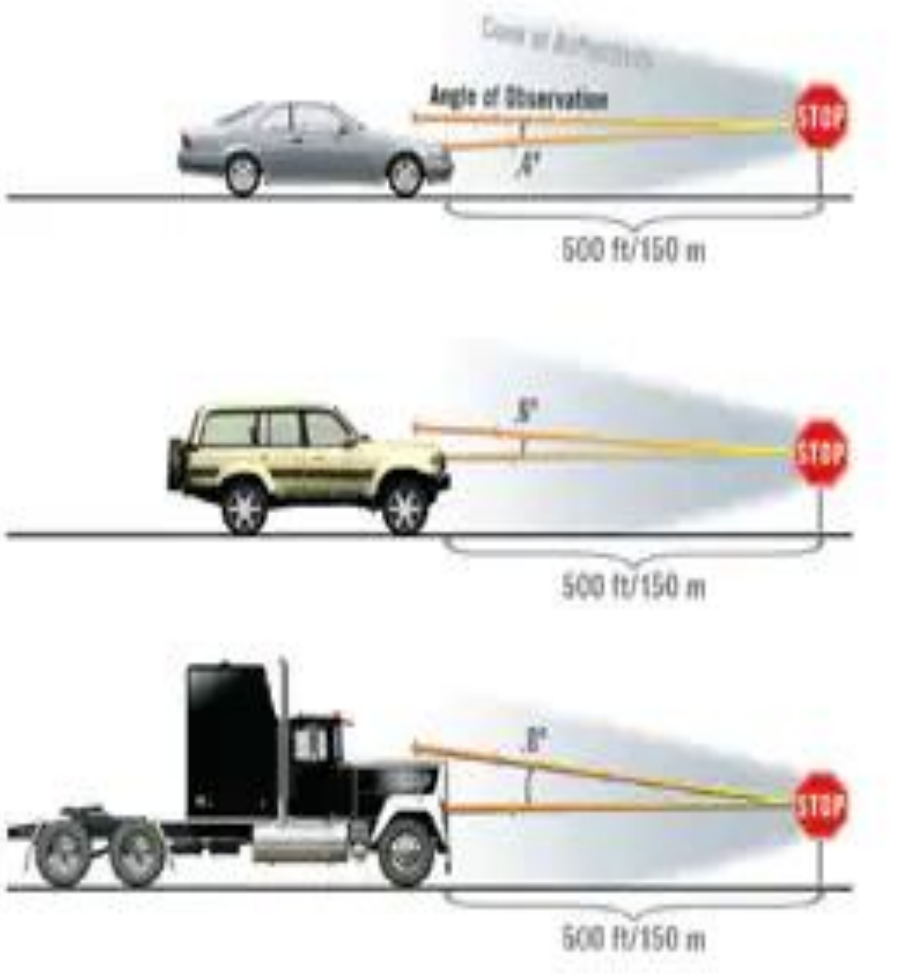


Retroreflection









Questions