Engineering Physics
Physics for Forestry

Oscilation and waves

Introduction

- <u>Oscillation</u> – a repeated cycle motion of a particle about an equilibrium position

- Displacement along *y* axis for simple harmonic motion (SHM):

$$y = A \sin(\omega t + \varphi), \quad \text{where}$$

***A* – amplitude of motion**

***ω* – angular frequency**

($\omega . t + \varphi$) – phase of motion

***φ* – phase constant – phase angle for time $t = 0$**

***T* – period - the time to complete one cycle, $[T] = s$**

$f = 1/T$ – frequency - number of cycles per second $[f] = s^{-1} = Hz$

Introduction

Speed **of SHM:** $v = \frac{dy}{dt} = \omega A cos(\omega t + \varphi)$

Acceleration **of SHM:** $a = \frac{dv}{dt} = \frac{d^2y}{dt^2} = -\omega^2 A sin(\omega t + \varphi) = -\omega^2 y$

- In SHM there is a constant interchange of energy between the kinetic and potential forms

- The kinetic energy is given by: $E_k = \frac{1}{2}mv^2 = \frac{1}{2}m\omega^2 A^2 cos^2(\omega t + \varphi)$

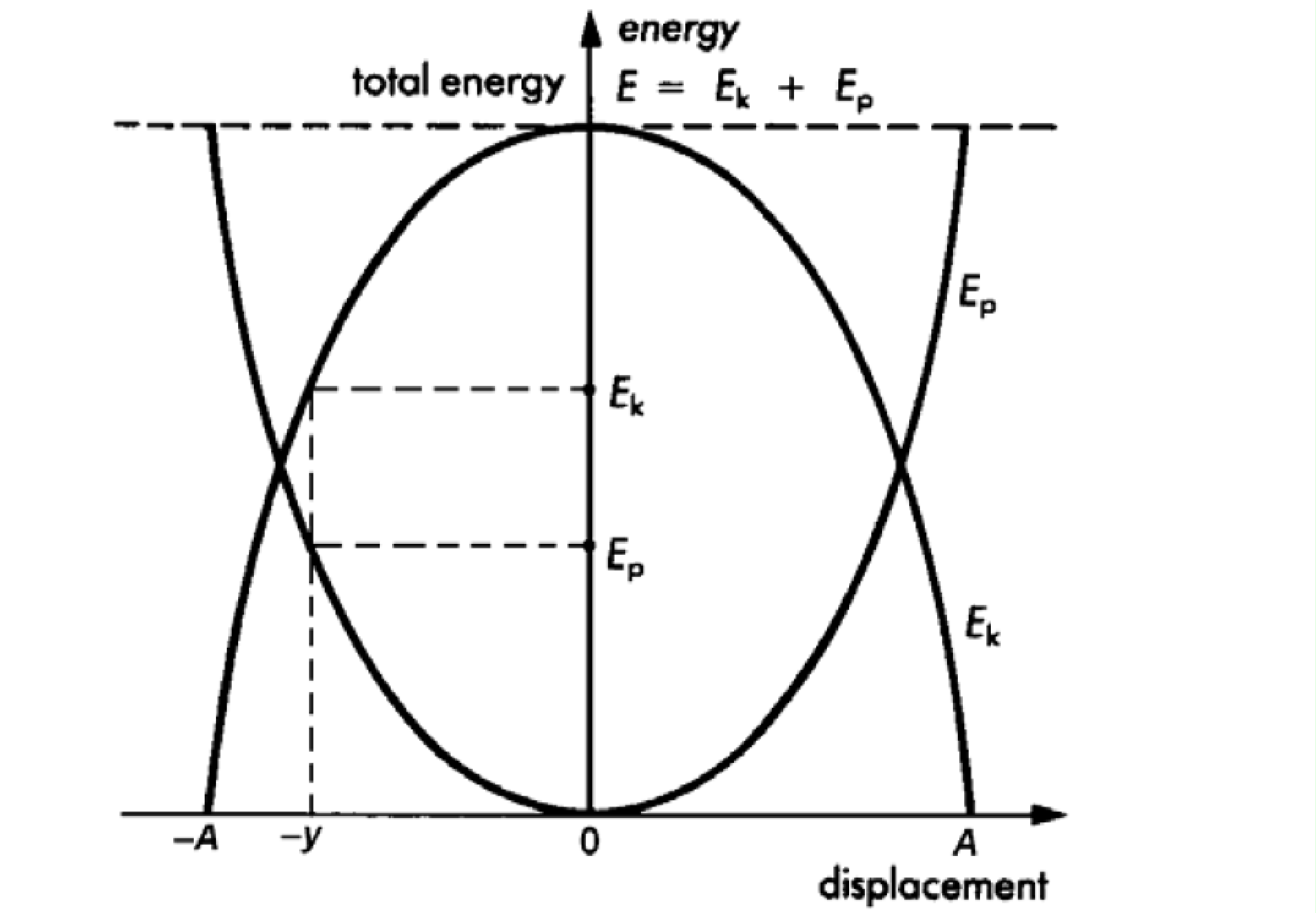
- The potential energy is given by: $E_p = \frac{1}{2}m\omega^2 y^2 = \frac{1}{2}m\omega^2 A^2 sin^2(\omega t + \varphi)$

- The total energy *E* – constant ; always the sum of E_k and E_p:

$$E = E_k + E_p = \frac{1}{2}m\omega^2 A^2$$

Introduction

Fig. shows the energy as the oscillator goes through a complete cycle:



Introduction

- <u>Wave motion</u> – a means of transferring energy from one point to another without there being any transfer of matter between the points

- *Mechanical waves* (e.g. sound waves) require a material medium to propagate

- *Electromagnetic waves* - electrical oscillations in which voltage, charge or current cycles around an equilibrium value - can propagate through a vacuum

- Mechanical waves – the propagation of the oscillatory motion of particles through space due to the elasticity of the environment

- *Transverse waves* – particles oscillate perpendicular to the motion of the wave (e.g., water rippling on the surface)

- *Longitudinal waves* – the particles of the environment oscillate parallel to the wave motion (e.g. sound waves in air)

Introduction

- The source of the waves oscillates harmonically ⇒ the plot of the displacement of the particles from the equilibrium position at a given time versus the distance from the source is also sinusoidal see Fig.

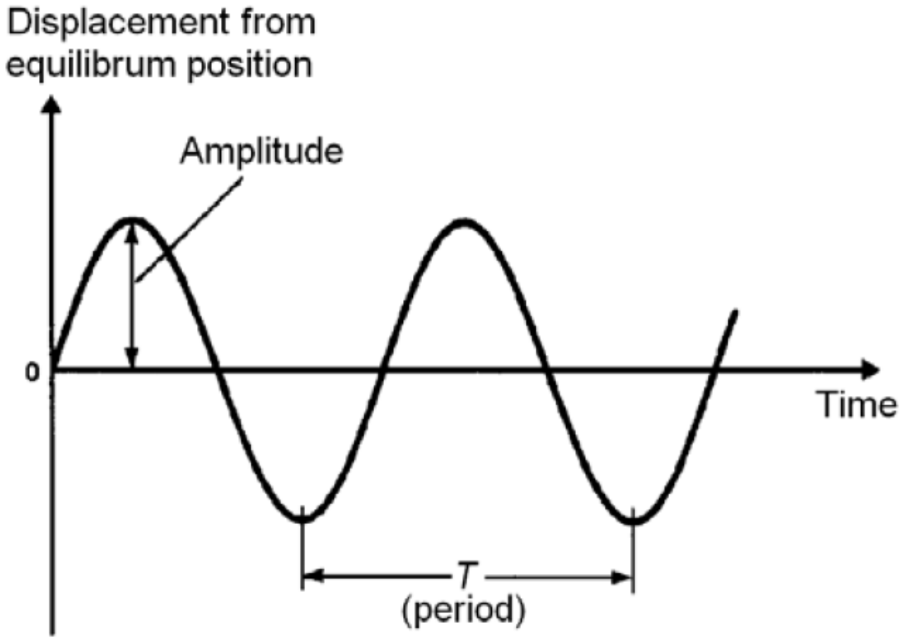
- The amplitude *A* of a single particle oscillation; also the amplitude of the wave

The wavelength *λ* – the distance between any nearest particles at the same phase of their motion [*λ*] = m

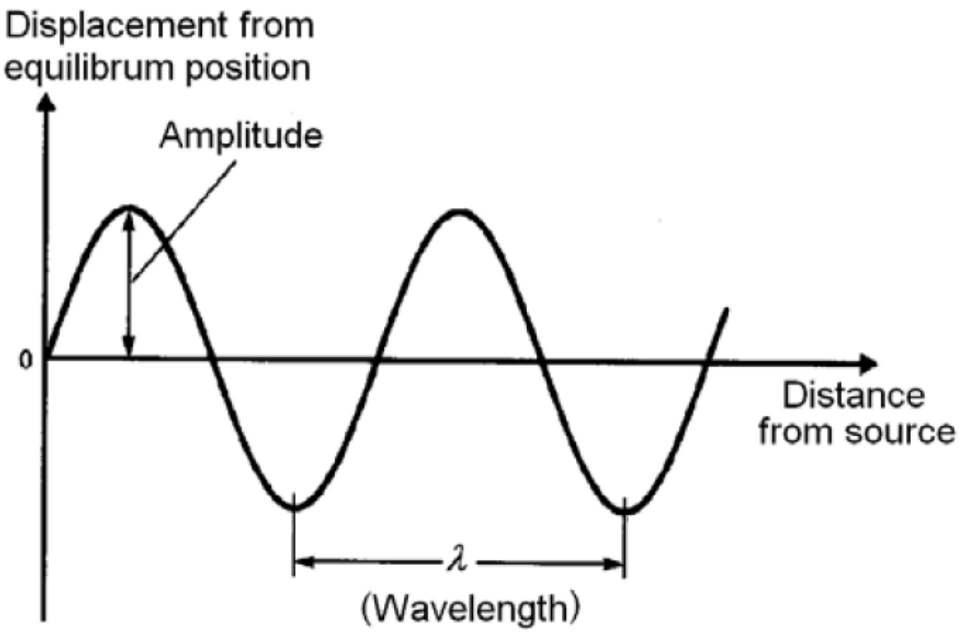
- The period *T* – the time it takes any particle to complete one oscillation; also the time it takes a wave to travel one wavelength

- The frequency *f* – the number of cycles of any particle in one second; also the number of wavelengths that pass through a fixed point in one second [*f*] = Hz

Introduction



Displacement against time for a
single particle in harmonic wave



Displacement against distance for
particles in a harmonic wave

Introduction

The <u>speed of wave</u> *v* – the distance the wave travels in one second

- The product of the number of cycles per second (frequency) *f* and the wavelength *λ*: $v = f\lambda$

- The energy transferred by an oscillator is proportional to the square of its amplitude ⇒ a proportionality between the square of the amplitude of the wave and its intensity

- The intensity *I* at a given point – the energy per second passing through the unit surface in the direction along the normal

- The intensity *I* at a distance *r* from a point source of power *P* which radiates waves in all directions in a non-absorbing medium:

$I = \frac{P}{4\pi r^2}$ **, [*I*] = W/m^2** **($4\pi r^2$ - the area of a sphere of radius *r*)**

- The intensity *I*(*r*) of emitting waves – inversely proportional to the distance *r* from the source: $I(r) \sim 1 / r^2$

Acoustics

- Sound waves – longitudinal pressure waves travelling through a medium
- Sounds – produced by vibrating objects (strings, pipes, loudspeakers)
- The hearing range for humans – sounds of frequencies 20 Hz - 20 kHz

Example:

We assume that the speed of sound in air is about 333 m/s. If a lightning flash in a thunderstorm is followed by sound after 6 seconds, what is the distance between the lightning and the observer? Assume that light travels much faster than sound.

[d = 2 km]

Acoustics

- The speed of sound as any mechanical waves depends on the elastic and inertial properties of the medium:

- The speed of sound – in water about 1450 m/s, in steel 5900 m/s

- The intensity of a sound *I* – the energy of a sound wave per unit area per second: [*I*] = $J.m^{-2}.s^{-1} = W.m^{-2}$

- Average sound intensity range for human hearing:

hearing threshold **($I_0 = 10^{-12}$ W/m²) -** ***pain threshold*** **($I_{max} = 10^{2}$ W/m²) ⇒**

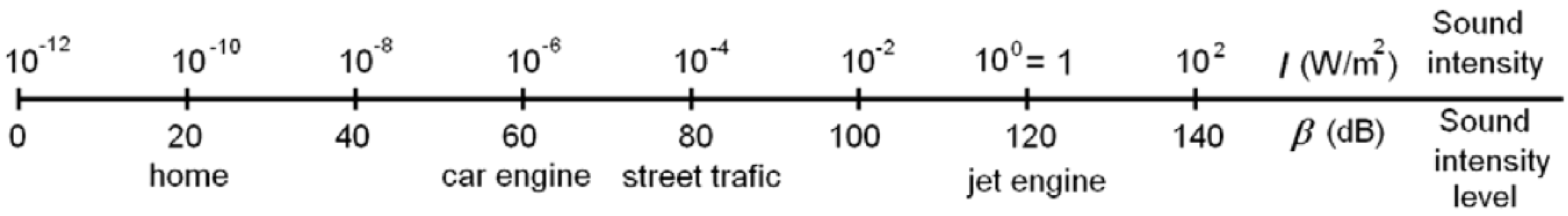
⇒ huge range of sound intensity values - 10^{14}

- Better to use a logarithmic scale:

The sound intensity level of the sound intensity *I*: $\beta = 10 \log \frac{I}{I_0}$

[*β*] = dB – decibel

Acoustics



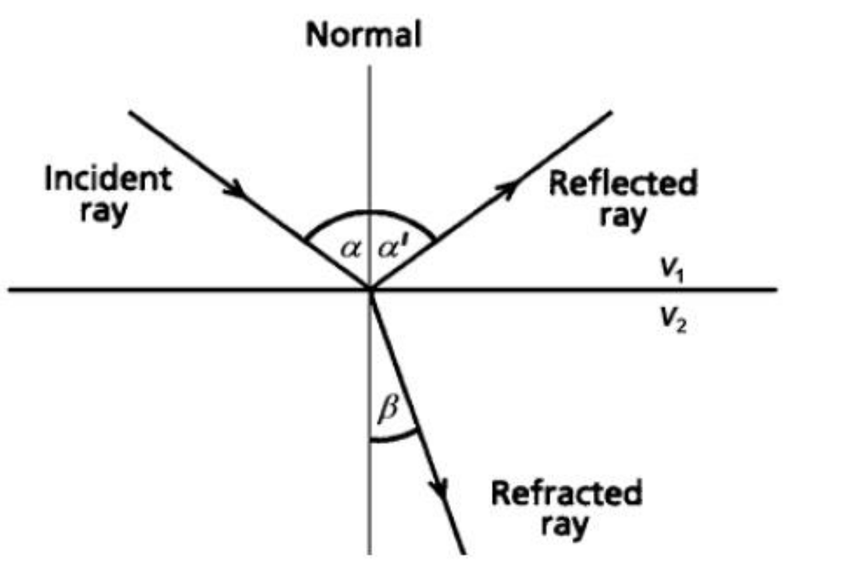
Example 6.15:

What sound intensity level corresponds to a sound intensity of 10^{-4} W/m^2?

[β = 80 dB]

Geometrical (Ray) Optics

- The rays show the direction of light propagation
- Geometric optics assumes that light moves in straight lines and presents laws that describe the reflection and refraction of light rays
- When rays strike a plane surface, their direction changes
- Light is reflected from the plane surface, and some light may pass from one medium to another transparent medium in which the speed of propagation changes - light refracts – see Fig.



Geometrical (Ray) Optics

<u>Law of reflection</u>: *α* = *α´* (alpha with a line)

- The angle of incidence *α* always equals the angle of reflection *α´*

<u>Law of refraction - Snell's law</u>:

- The ratio of the sine angle of incidence *α* to the sine angle of refraction *β*

is constant: $\frac{\sin\alpha}{\sin\beta} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$ **,**

where v_1 – the speed of light in the medium 1

v_2 – the speed of light in the medium 2

$n_1 = \frac{c}{v_1}$ **– *index of refraction* of a medium with the speed of light v_1**

$n_2 = \frac{c}{v_2}$ **– *index of refraction* of a medium with the speed of light v_2**

(*c* = $3 \cdot 10^8$ m/s – speed of light in vacuum)

Geometrical (Ray) Optics

Total reflection

- If light travels from the optically denser medium of n_1 into the optically thinner medium of n_2 ($v_1 < v_1$), then $\beta > \alpha$

- The *critical angle* α_m is reached when the refraction angle of the ray

$\beta = 90°$

- At angles α greater then the critical angle $\alpha > \alpha_m$ the ray does not pass to the second medium and it is *totally reflected*

Example 10.17:

The light ray passes from the glass into the air. Calculate the angle of refraction if the angle of incidence is 30° and the refractive index of the glass is 1.5. Calculate the speed of light in the glass.

[$\beta = 48°35'$, $v_1 = 2 \cdot 10^8$ m/s]

Geometrical (Ray) Optics

Image creation

- Reflection or refraction of light can be used to create an image of a physical object using mirrors and lenses

Mirror – a surface that reflects most of the light that falls on it

- When rays of light fall on a mirror, the law of reflection tells how the rays are reflected

- A *plane mirror* – a flat reflecting surface

- The image formed by a plane mirror is always the same size as the object; is as far behind the mirror as the object in front of the mirror

- The image is laterally inverted

- When you look at yourself in a plane mirror, you do not see yourself exactly as you appear to others, but with the right and left sides reversed

Geometrical (Ray) Optics

- *Spherical mirrors* – made up of the surfaces of spheres

Concave mirrors have a reflecting surface in the inner parts of the sphere

Convex mirrors have a reflecting surface in the outer parts of the sphere

- Position of the image compared to the position of the object:

- The image can be *upright* or *inverted*

- Height of the image compared to the height of the object:

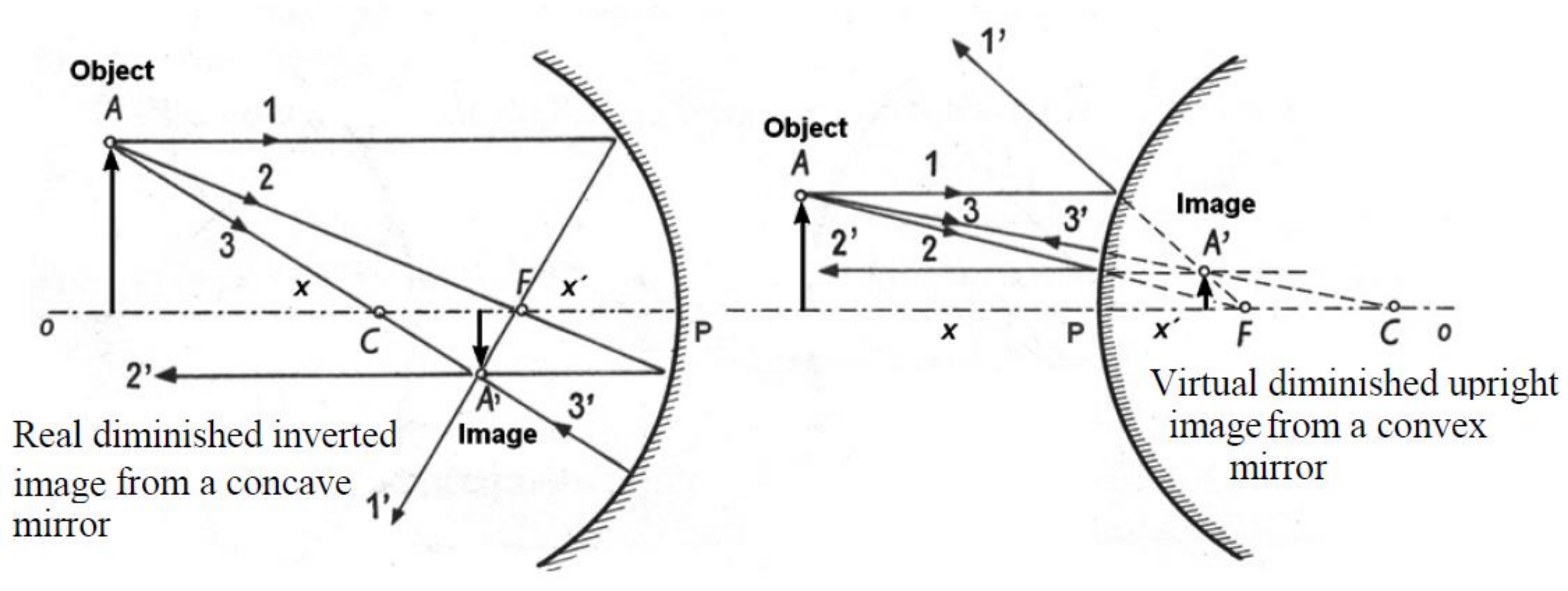
- The image can be *enlarged*, *diminished* or the *same size* as the object

- A *virtual image* – an image from which light rays seem to pass and which cannot be created on a screen

- A *real image* – one through which light rays actually pass and can be displayed on a screen

Geometrical (Ray) Optics

Graphical construction of image – see Fig.



C – the centre of curvature of the sphere from which the mirror's part of surface is formed,

P – the top of the mirror,

CP – the radius of curvature *r* of the mirror

Geometrical (Ray) Optics

- The distance from the focus F to the top of the mirror P – the *focal length f*

- The focal length *f* is related to the radius of curvature *r* of the mirror by the relation: $f = r / 2$

- For each type of spherical mirror there are three main rays whose paths can be determined

1 - the incident ray parallel to the optical axis is reflected to the focus F,

2 - the incident ray passing through focus F is reflected back parallel to the optical axis,

3 - the incident ray passing through the centre of curvature C is reflected back along its original path

Geometrical (Ray) Optics

Calculation of image properties

- To calculate image position, the mirror formula (equation) is used:

$\frac{1}{x} + \frac{1}{x'} = \frac{1}{f}$ **(*f* = *r* / 2) , where**

x **– object-mirror distance,**

x' **– image-mirror distance,**

f **– focal length of mirror,**

r **– radius of curvature of mirror**

Lateral magnification m **– the ratio of the image height h_i to the object height h_o:** $m = \frac{h_i}{h_0} = -\frac{x'}{x}$

Geometrical (Ray) Optics

Sign convention for these two equations:

- All distances are measured to the top P of the mirror

- The distances in front of the mirror are of positive algebraic sign

- The distances behind the mirror are of negative algebraic sign

- This is also true for focal distances: $f > 0$ concave mirror, $f < 0$ convex mirror

- Positive values $x' > 0$ – for real images

- Negative values of $x' < 0$ – for virtual images

- The object and image heights, h_o and h_i – positive for points above the optical axis, negative for points below the optical axis

Geometrical (Ray) Optics

<u>Lens</u> – a curved, transparent material used to refract the light that falls on it

- Light is refracted from the first material (usually air) into the lens, passes through the lens, and then refracts back into the first material

- *Converging lens* - incident light rays parallel to the optical axis converge to the *focus (focal point)* F after refraction on the lens surfaces

- *Diverging lens* - incident light rays parallel to the optical axis diverge from the *focus (focal point)* F after refraction on the lens surfaces

- *Focal length f* – the distance between the optical centre O and the focal point F

***The power of lens P*: $P = \frac{1}{f}$ ($\text{Power} = \frac{1}{\text{focal length in metres}}$)**

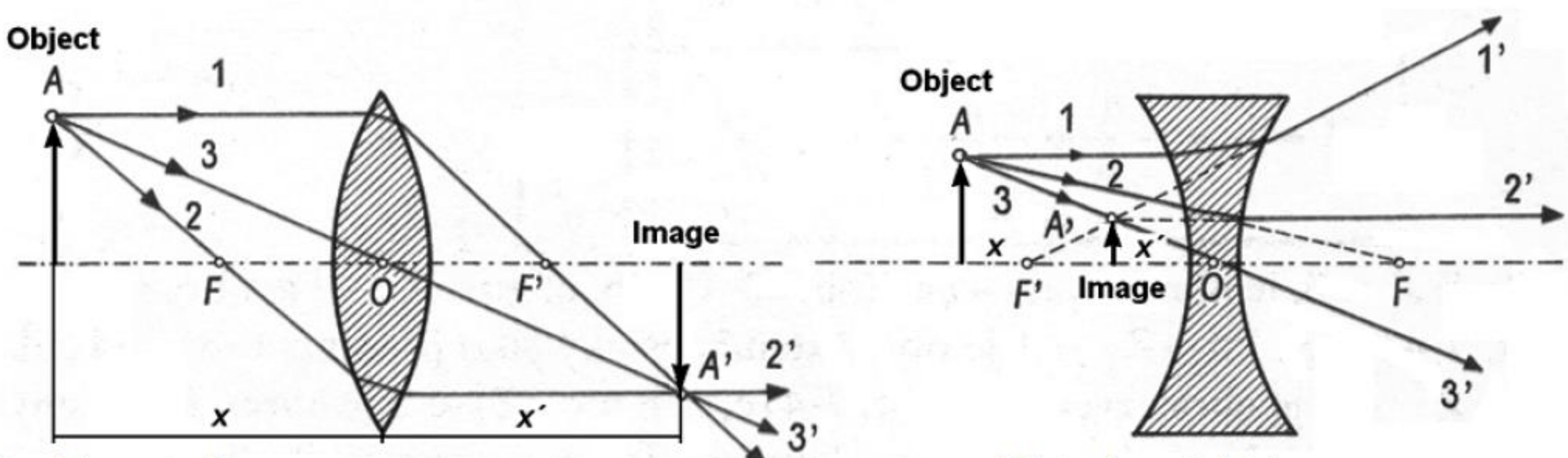
[*P*] = m^{-1} = D (dioptre)

Geometrical (Ray) Optics

Graphic construction of the image – see Fig.

- If the paths of two arbitrary rays from one point on an object are known, the position of its image (the intersection of the two refracted rays) can be determined

- For each type of lens there are three main rays whose paths can be determined



Real inverted image
from a converging lens

Virtual upright image
from a diverging lens

Geometrical (Ray) Optics

1 - the incident ray parallel to the optical axis is refracted to the focus F´ on the other side of the lens,

2 - the incident ray passing through the F focus is refracted parallel to the optical axis,

3 - the incident ray passing through the optical centre O does not change its direction

<u>Calculation of image properties</u>

- To calculate image position, the lens formula (equation) is used:

$\frac{1}{x} + \frac{1}{x'} = \frac{1}{f}$ **, where**

x **– object-lens distance,**

x' **– image-lens distance,**

f **– focal length of lens**

Geometrical (Ray) Optics

Lateral magnification m **– the ratio of the image height h_i to the object height h_o:** $m = \frac{h_i}{h_0} = -\frac{x'}{x}$

Sign convention for these two equations:

- All distances are measured from the optical centre O of the lens,

- The object distance – positive if the object is in front of the lens,

- The image distance – positive if the image is behind the lens and negative if the image is in front of the lens (positive values of $x' > 0$ for real images, negative values of $x' < 0$ for virtual images),

- The focal length – positive for a converging lens $f > 0$ and negative for a diverging lens $f < 0$,

- The object and image heights h_o and h_i – positive for points above the principal axis and negative for points below the principal axis