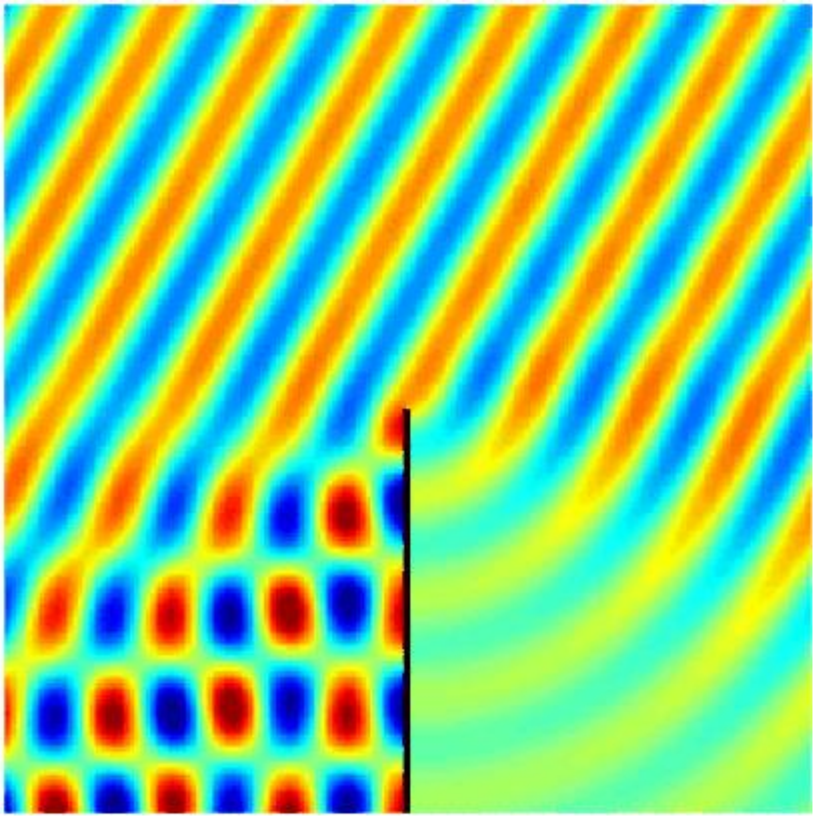


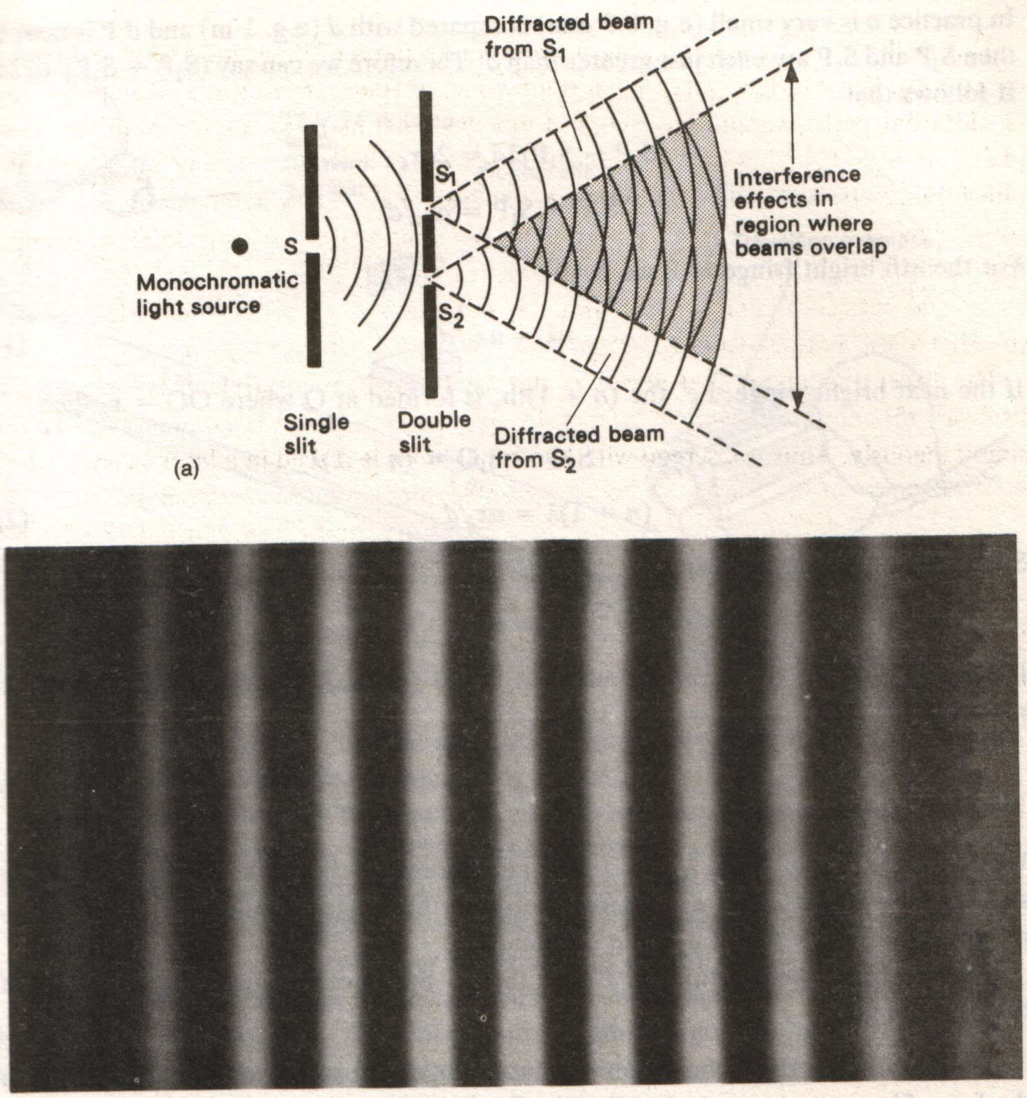

Diffracted beam from S_1
Interference effects in region where beams overlap
S
S_1
S_2
Monochromatic light source
Single slit
Double slit
Diffracted beam from S_2
(a)
(b)

Fig. 8.3

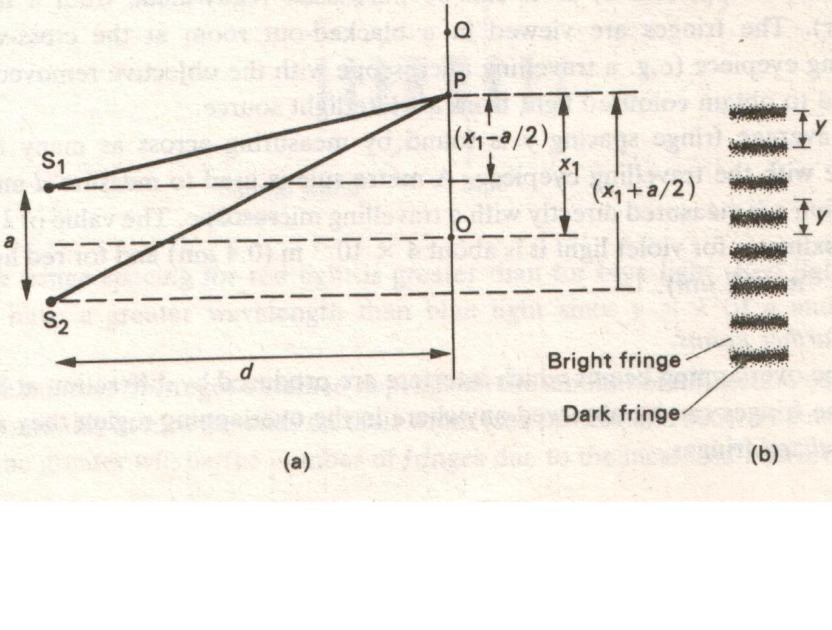
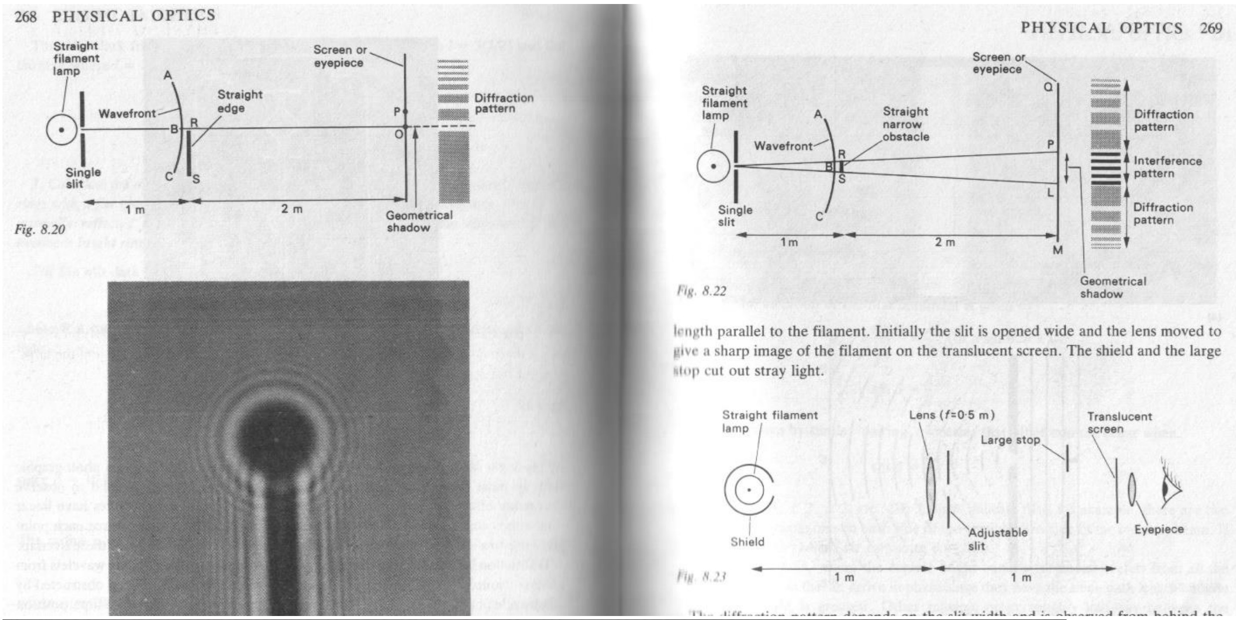

Q
P
S_1
$(x_1 - a/2)$
x_1
$(x_1 + a/2)$
O
a
S_2
d
y
y
Bright fringe
Dark fringe
(a)
(b)

Fig. 8.4


268 PHYSICAL OPTICS
Straight filament lamp
Single slit
Wavefront
A
B
C
R
S
Straight edge
Screen or eyepiece
P
O
Diffraction pattern
Geometrical shadow
1 m
2 m
Fig. 8.20
PHYSICAL OPTICS 269
Straight filament lamp
Single slit
Wavefront
A
B
C
R
S
Straight narrow obstacle
Screen or eyepiece
Q
P
L
M
Diffraction pattern
Interference pattern
Diffraction pattern
Geometrical shadow
1m
2 m
Fig. 8.22
length parallel to the filament. Initially the slit is opened wide and the lens moved to give a sharp image of the filament on the translucent screen. The shield and the large stop cut out stray light.
Straight filament lamp
Shield
Lens (f=0·5 m)
Adjustable slit
Large stop
Translucent screen
Eyepiece
1 m
1 m
Fig. 8.23

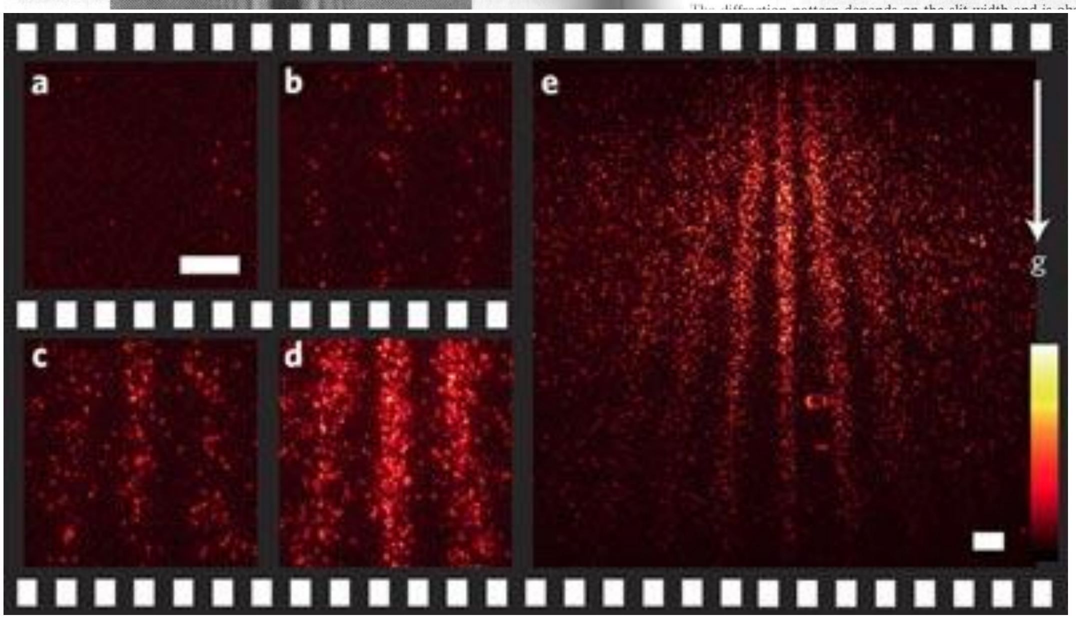
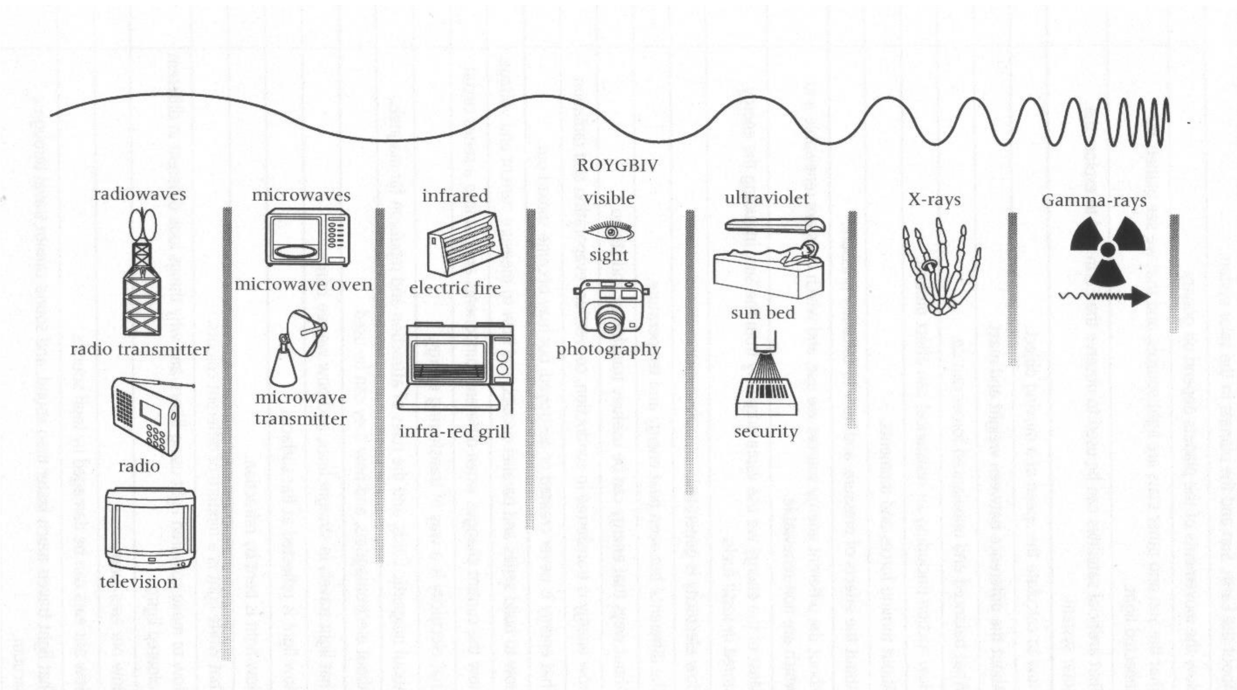

a
b
c
d
e
g

Table 22.1 The electromagnetic spectrum

Type	Frequency	Wavelength	How made	Uses	Photon energy
long-wave radio	~250 kHz	~1200 m	oscillating currents in aerials	radio	$\sim 10^{-28}$ J
medium-wave radio	~1000 kHz (1 MHz)	~300 m	oscillating currents in aerials	radio	$\sim 10^{-27}$ J
short-wave radio	~10 MHz	~30 m	oscillating currents in aerials	radio	$\sim 10^{-26}$ J
VHF	~100 MHz	~3 m	oscillating currents in aerials	radio	$\sim 10^{-25}$ J
UHF	~400 MHz	~1 m	oscillating currents in aerials	television	$\sim 10^{-25}$ J
microwaves	~2.5 GHz	~10 cm	directly produced in waveguides	radar, cooking, communicating	$\sim 10^{-24}$ J
infra-red	$\sim 10^{14}$ Hz	~1 μm (> 700 nm)	hot bodies, LEDs	night-sights, heating, short-distance communication	$\sim 10^{-19}$ J ~1 eV
visible	$\sim 5 \times 10^{14}$ Hz	700 – 400 nm	very hot bodies, LEDs	seeing, etc	2 – 3 eV
ultra-violet	$> 7.5 \times 10^{14}$ Hz	<400 nm	extremely hot bodies, sparks, discharge tubes	sun-tanning, detecting invisible marking, sterilising	> 3 eV
X-rays	$\sim 10^{18}$ Hz	$\sim 10^{-10}$ m	stopping fast electrons	X-raying people and materials	~10 000 eV
gamma rays (overlap with X-rays)	$\sim 10^{20}$ Hz	$\sim 10^{-12}$ m	nuclear decay	X-raying thick objects, killing cancerous cells, sterilising	~1 MeV $\sim 10^{-13}$ J
cosmic rays	very high	very short	from distant parts of the Universe	just cause a hazard	up to tens of joules


ROYGBIV
radiowaves
radio transmitter
radio
television
microwaves
microwave oven
microwave transmitter
infrared
electric fire
infra-red grill
visible
sight
photography
ultraviolet
sun bed
security
X-rays
Gamma-rays

Section D Waves

D1(T) Investigating oscillations

When a mass hanging from a vertical spring is pulled down and released it bobs up and down. Studying this simple arrangement gives a clear picture of the essential features of any oscillating system.

1 Does the time period depend on the amplitude of the oscillations?

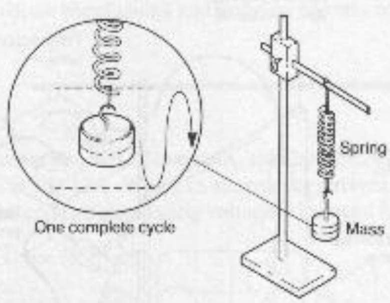


Fig 1A Timing oscillations

Displace a mass downwards from equilibrium by a measured distance and release it (see Fig 1A). Time 20 complete oscillations and work out the time period, *T*. Repeat the measurement several times. Estimate and record the probable errors in your measurements.

Repeat this for different initial displacements. Record all your measurements in a table.

> ***Question***
>
> **1** Present your results as a graph, showing the experimental errors in each measurement on your graph. What conclusions can you draw from your results?

2 How does the displacement vary with time after the mass is released?

Use a tickertimer and tickertape to record the motion of the mass for the first half-cycle after release. Fig 1B shows one way to do this.

Use your tape to make a graph of displacement against time. From the graph, work out the time period.

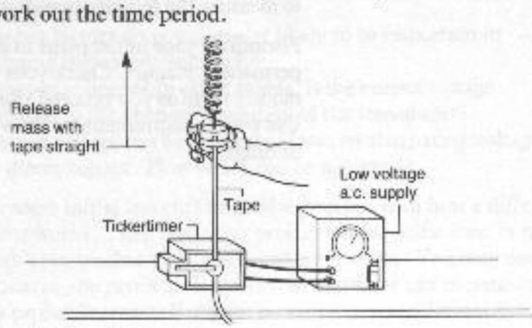


Fig 1B Recording the motion

Questions

2 Sketch graphs on the same axes to show how the velocity and the acceleration vary with time. What can you say about the acceleration in relation to the displacement?

3 Describe the motion of the mass after release. The amplitude gradually becomes smaller and smaller. Why?

How does the time period depend on the mass?

Measure the time period for different masses hanging from the spring. Record your measurements and estimate the probable error in them.

Questions

4 The time period, T may be worked out from the equation:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where m = mass hung on the spring and k = the spring constant.

Plot a suitable graph to confirm the above relationship and work out a value for k.

5 Determine the spring constant, k, by loading the spring with different known weights and measuring the extension. Plot a graph of your measurements and work out a value for k from this graph. Compare this value of k with the value obtained above.

C2(I) The simple pendulum

Measuring the time period, T

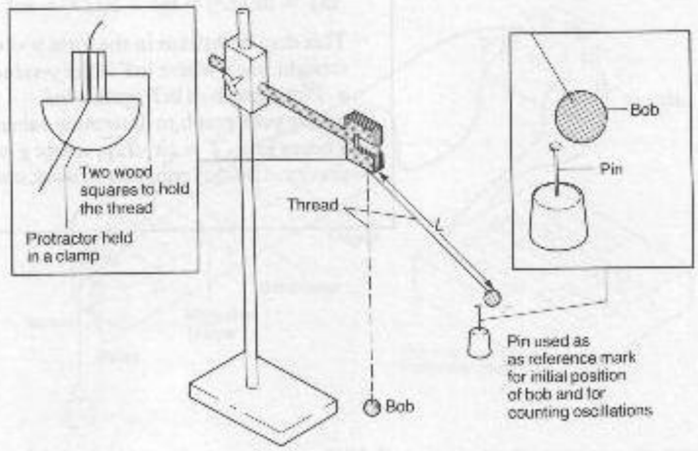


Fig 2A The simple pendulum

Set up the pendulum as in Fig 2A. Displace the pendulum by a measured angle from its equilibrium position and time 20 complete oscillations.

How reliable is your timing? Repeat the measurement ten times, displacing the pendulum by the same angle each time. Record your measurements.

Questions

1 Work out the average timing for 20 oscillations, T_{20}.
2 From the spread of measurements, estimate the probable error for T_{20}.
3 How many times is it necessary to make the measurements to obtain a reliable result?

2 Does the time period depend on the amplitude of oscillations?

Displace the pendulum by 5° from equilibrium and time 20 oscillations after it has been released. Repeat the timings to obtain a reliable measurement. Record your measurements and work out the time period, T.

Repeat and record the measurements for initial displacement, θ, = 10°, 15°, 20°, 25° and 30°.

Question

4 Plot a graph of T (on the vertical axis) against θ. Use your graph to decide if T depends on θ.

3 How does the time period depend on length?

Measure the time period, T, for at least five different lengths, L. For each timing the initial displacement should not exceed 10°. Record all your measurements in a table.

Questions

5 Assume the relationship between T and L is of the form $T = kL^n$, where k and n are constants. Using the theory of logarithms:

$$\ln T = \ln(kL^n) = \ln k + \ln(L^n) = \ln k + n\ln L$$

This may be written in the form $y = mx + c$ (the equation for a straight line), where $\ln T$ is the y-value and $\ln L$ is the x-value.
a Plot a graph of $\ln T$ against $\ln L$.
b Use your graph to determine values for n and k.
6 Theory gives $T = 2\pi\sqrt{L/g}$, where g is the acceleration due to gravity. Use this equation to work out a value for g.

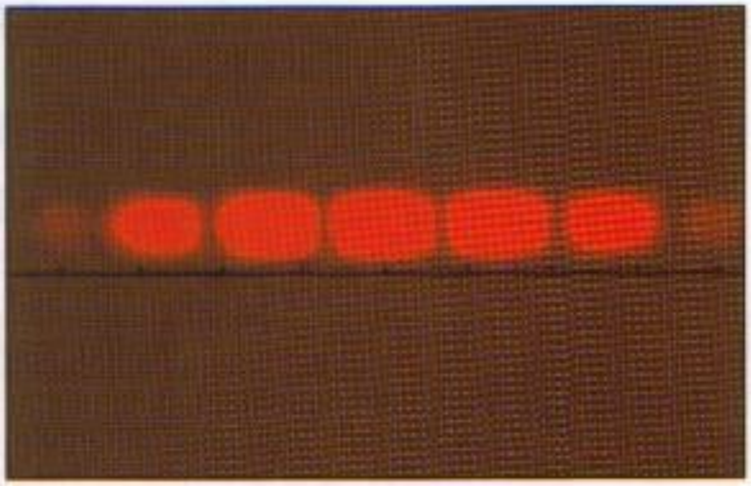


Figure 16.4 Superposition pattern for laser light through a double slit

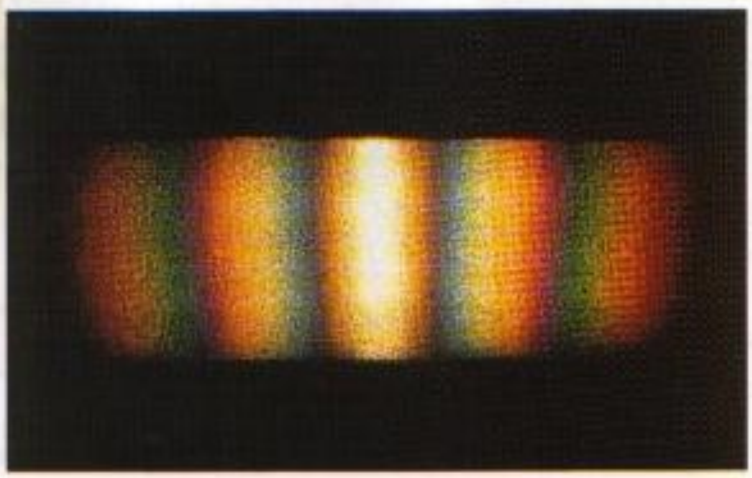


Figure 16.5 Superposition pattern caused by white light through a double slit

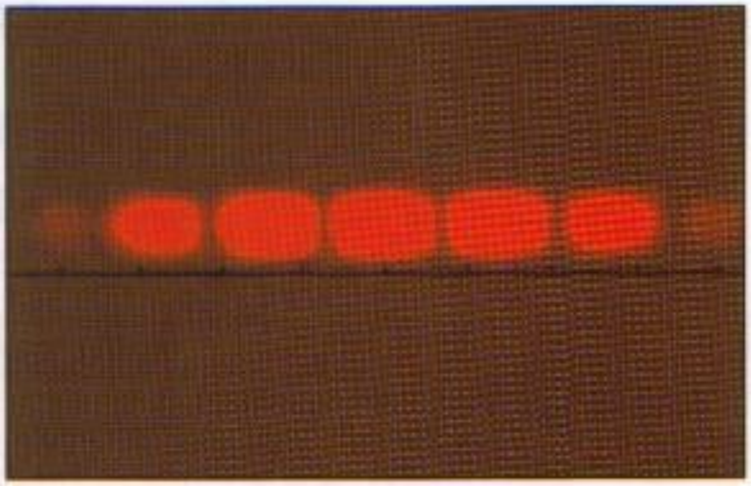


Figure 16.4 Superposition pattern for laser light through a double slit

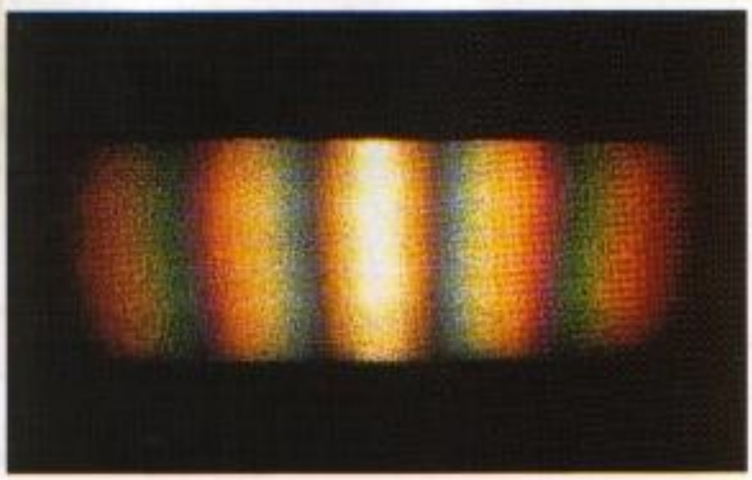
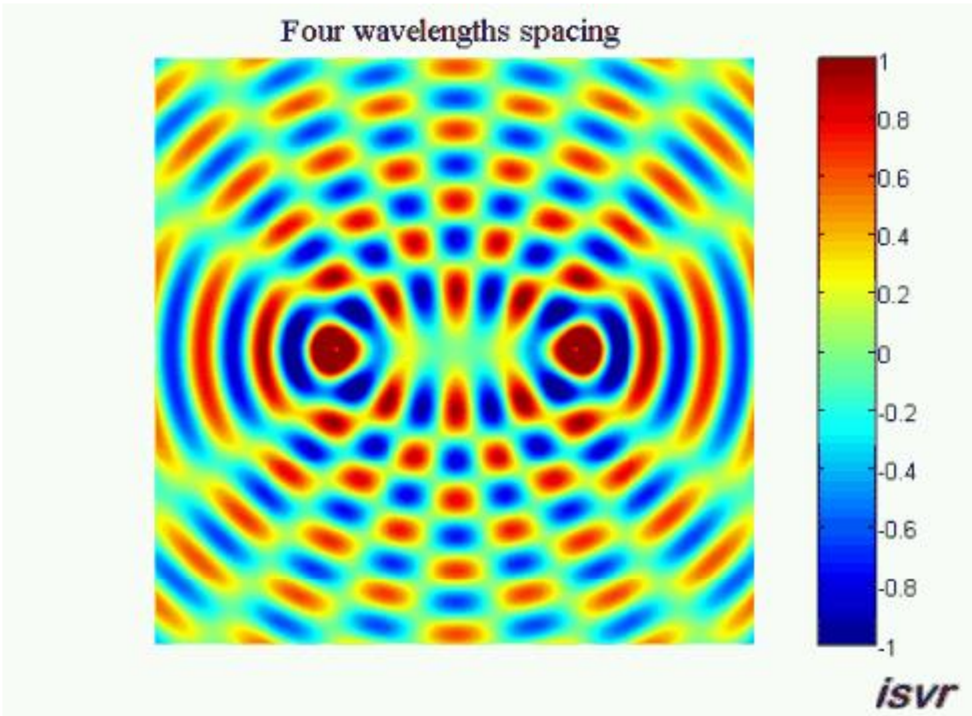
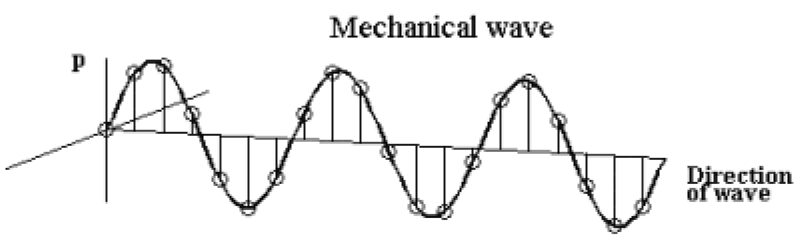
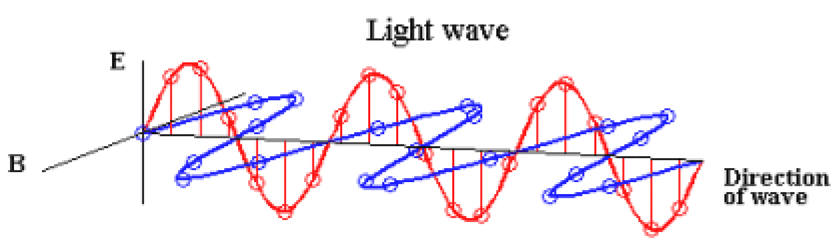
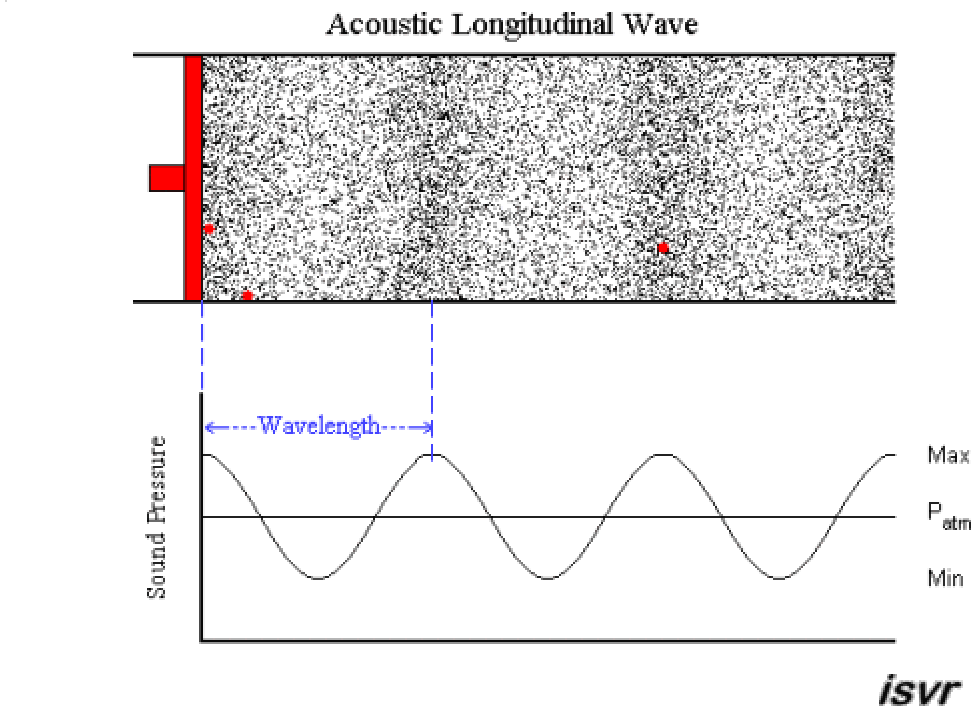


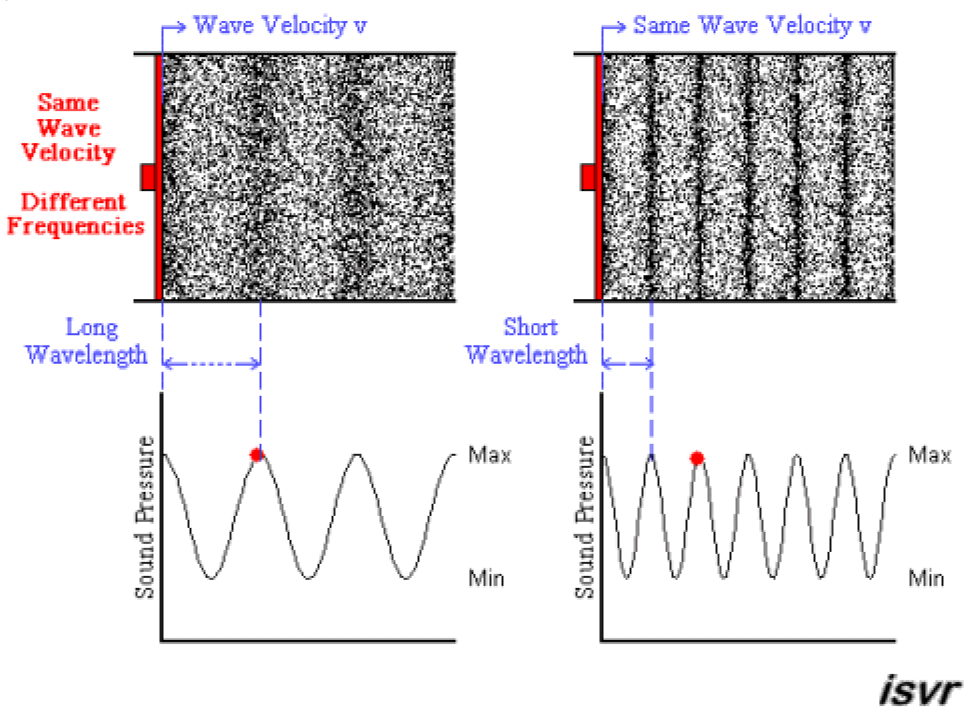
Figure 16.5 Superposition pattern caused by white light through a double slit

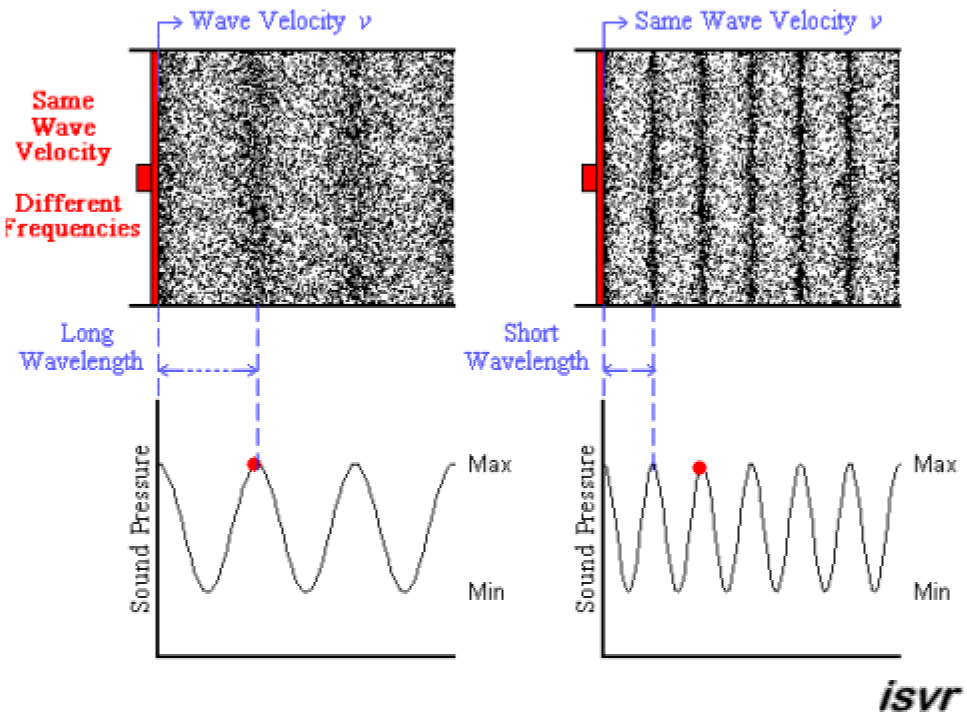

Four wavelengths spacing
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

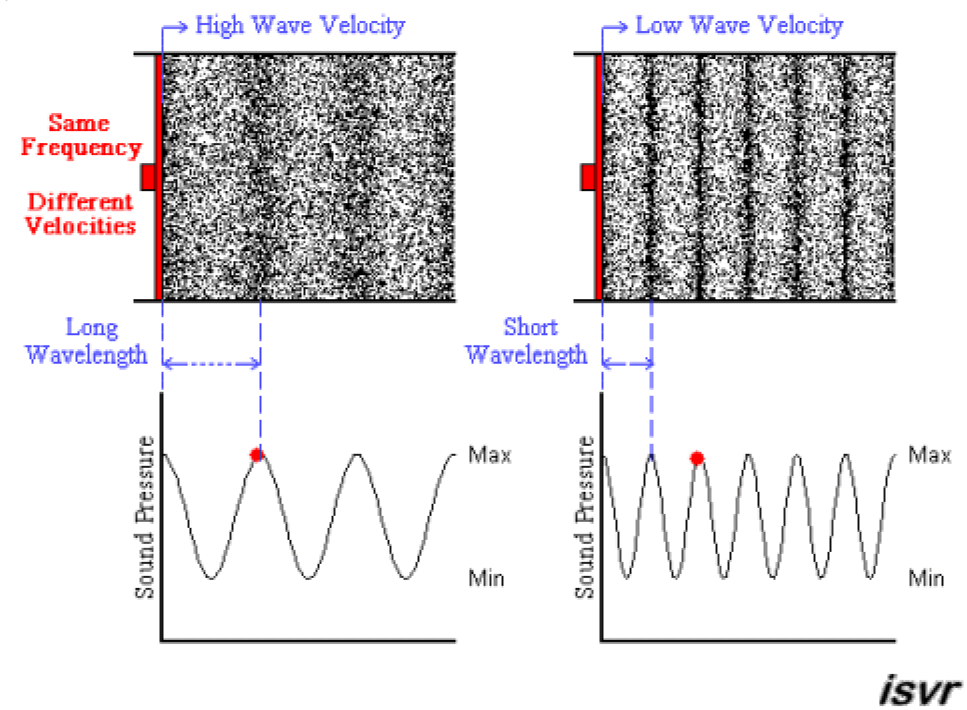

Mechanical wave
p
Direction of wave


Light wave
E
B
Direction of wave

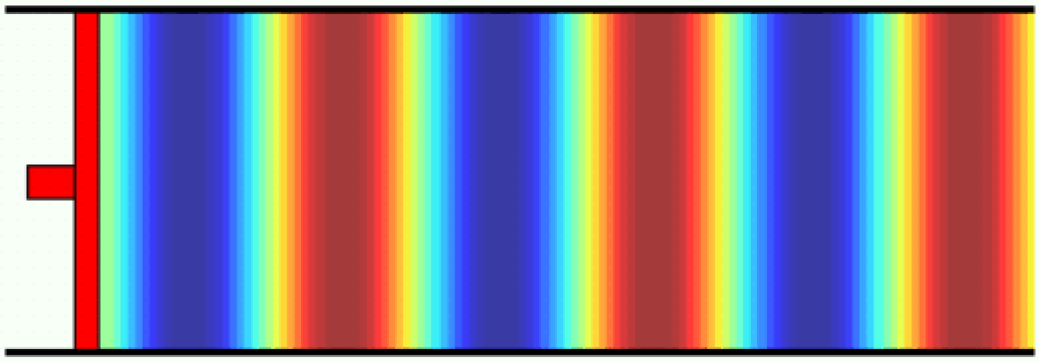

Acoustic Longitudinal Wave
Wavelength
Sound Pressure
Max
Patm
Min
isvr


Wave Velocity v
Same Wave Velocity v
Same Wave Velocity
Different Frequencies
Long Wavelength
Short Wavelength
Sound Pressure
Max
Min
Sound Pressure
Max
Min
isvr

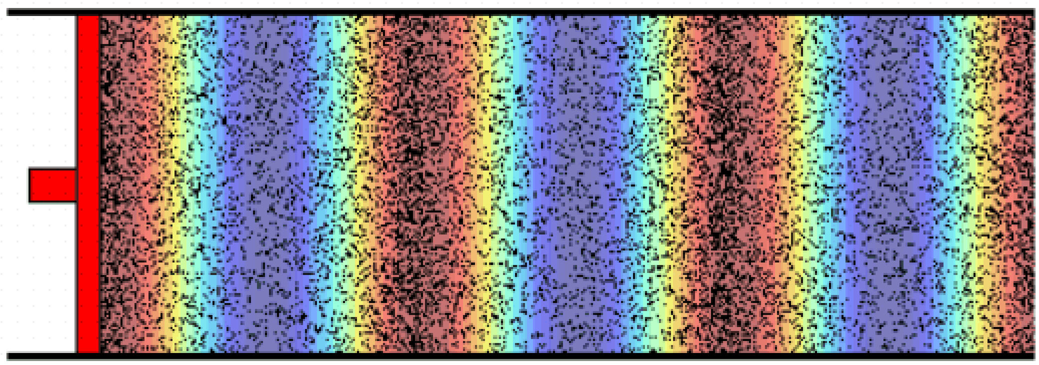

Wave Velocity v
Same Wave Velocity v
Same Wave Velocity
Different Frequencies
Long Wavelength
Short Wavelength
Sound Pressure
Max
Min
Sound Pressure
Max
Min
isvr


High Wave Velocity
Low Wave Velocity
Same Frequency
Different Velocities
Long Wavelength
Short Wavelength
Sound Pressure
Max
Min
Sound Pressure
Max
Min
isvr

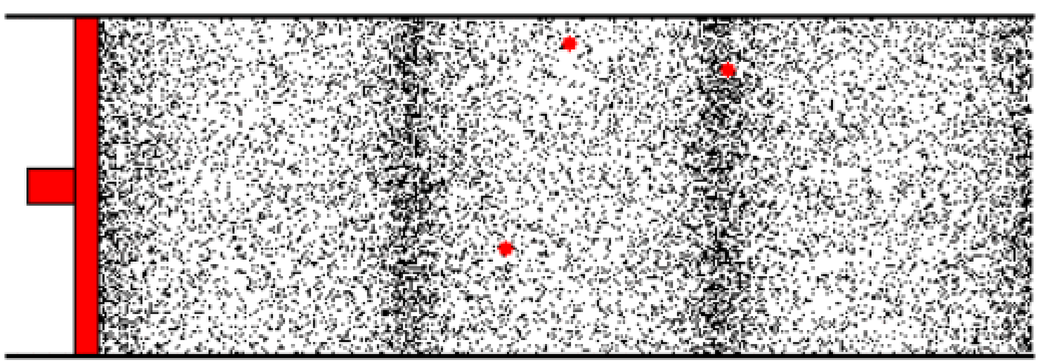
Longitudinal Wave

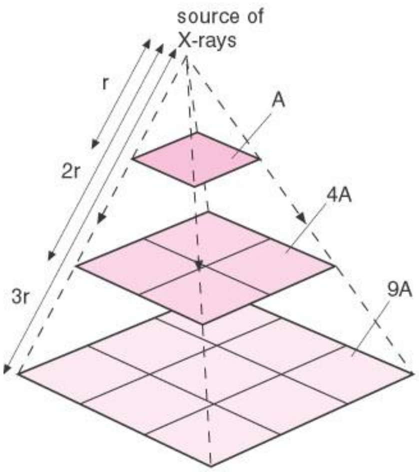


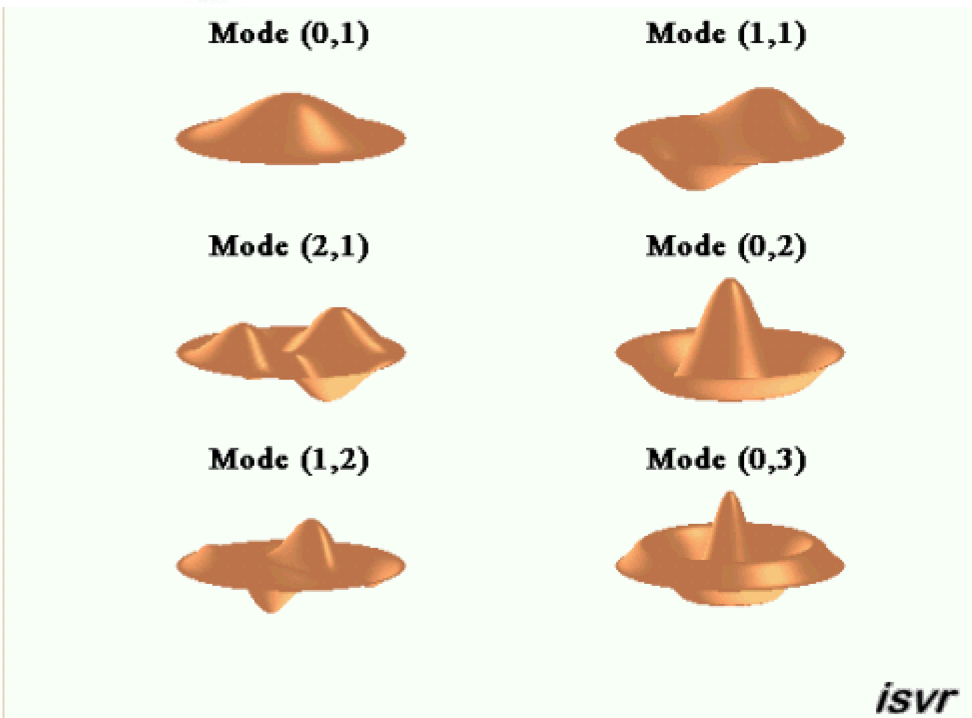
Longitudinal Wave

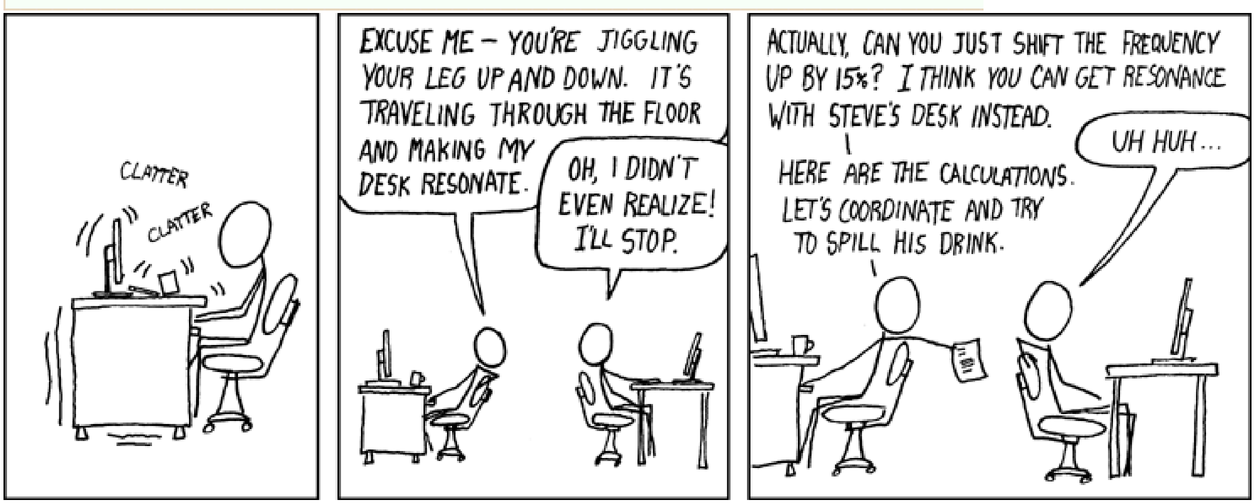


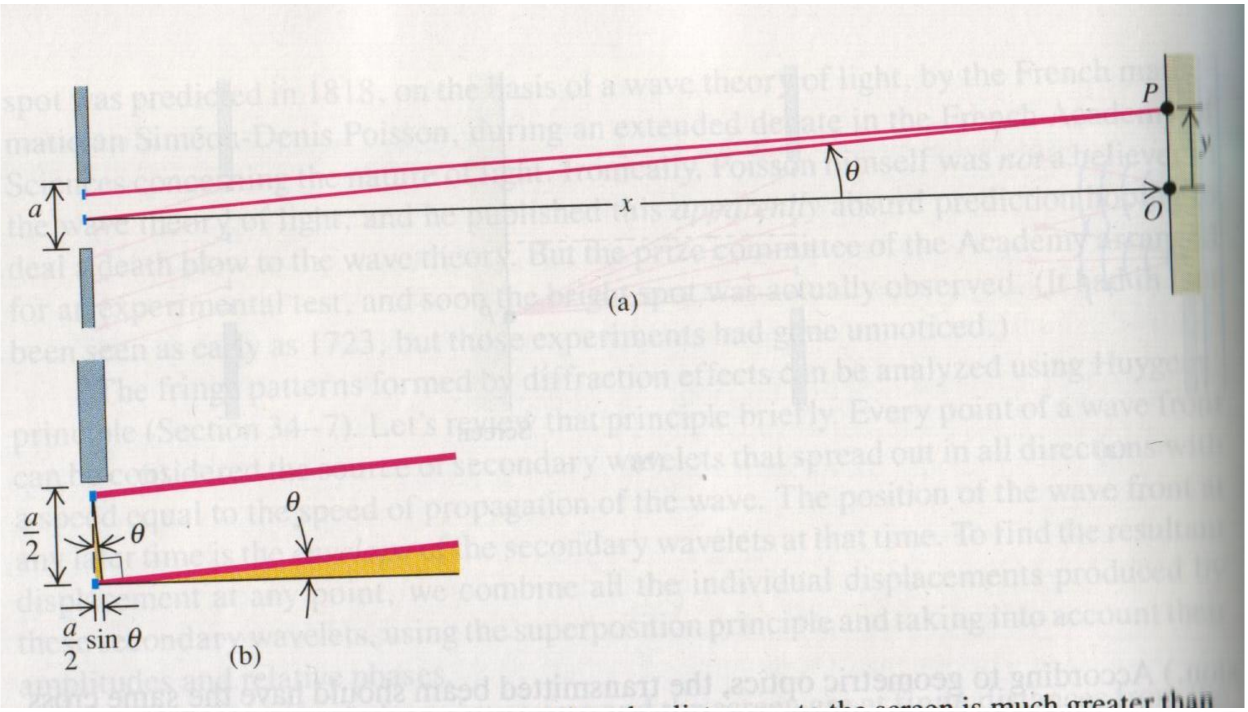
Longitudinal Wave




source of
X-rays
r
2r
3r
A
4A
9A

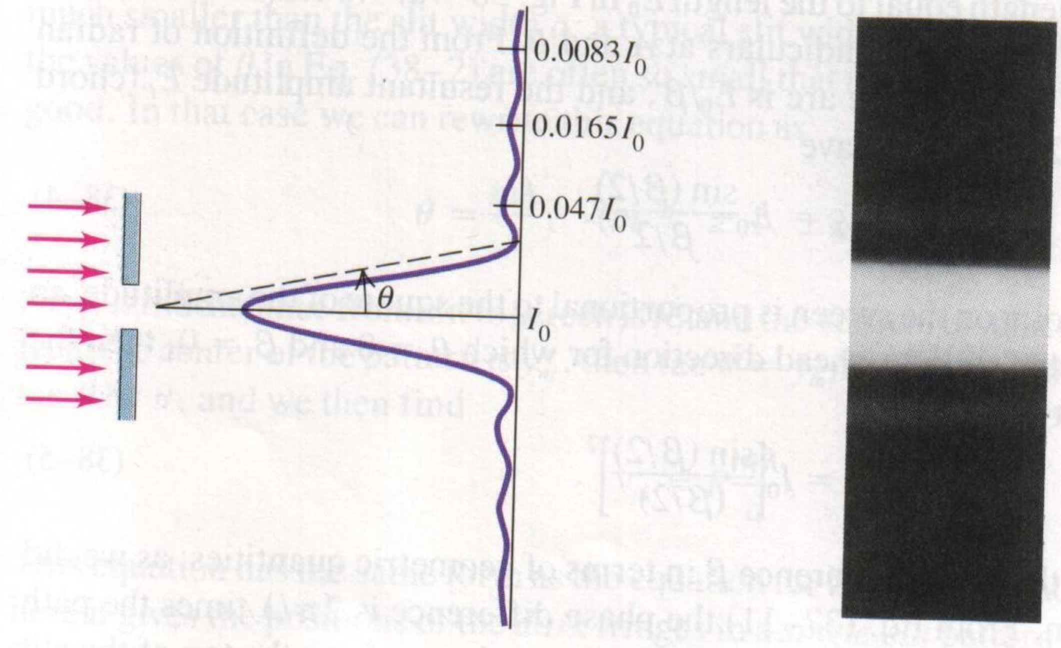

Mode (0,1)
Mode (1,1)
Mode (2,1)
Mode (0,2)
Mode (1,2)
Mode (0,3)
isvr


CLATTER
CLATTER
EXCUSE ME – YOU'RE JIGGLING YOUR LEG UP AND DOWN. IT'S TRAVELING THROUGH THE FLOOR AND MAKING MY DESK RESONATE.
OH, I DIDN'T EVEN REALIZE! I'LL STOP.
ACTUALLY, CAN YOU JUST SHIFT THE FREQUENCY UP BY 15%? I THINK YOU CAN GET RESONANCE WITH STEVE'S DESK INSTEAD.
HERE ARE THE CALCULATIONS. LET'S COORDINATE AND TRY TO SPILL HIS DRINK.
UH HUH...



(a)

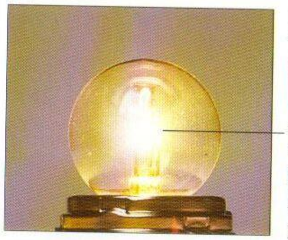
(b)



(a) (b)

in the incoming light.

SOURCES OF LIGHT

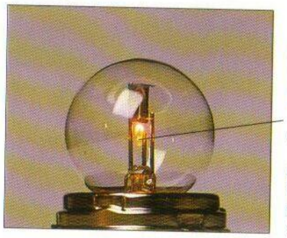


BRIGHT FILAMENT LAMP

This spectrum shows which colours are produced

All colours of light together combine to produce white

BRIGHT FILAMENT LAMP
With a high **electric current**, the whole spectrum of visible light is produced (see p. 39).



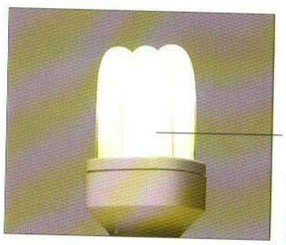
DIM FILAMENT LAMP

Red, yellow, and green light combine to produce orange

Lamp appears orange

No blue light produced

DIM FILAMENT LAMP
With a smaller current, the **temperature** of the **filament** (see pp. 32-33) is low.



FLUORESCENT LAMP

Lamp produces certain colours in each part of the spectrum

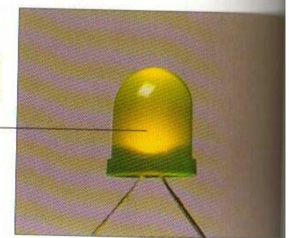
All three types of cone are stimulated and lamp appears white

FLUORESCENT LAMP
In a **fluorescent** lamp, chemicals called **phosphors** produce colours in many parts of the spectrum.

LED produces colours in the green part of the spectrum

LED appears green

GREEN LED
An LED (light-emitting diode) is made of a **semiconductor**, and produces certain colours of light.

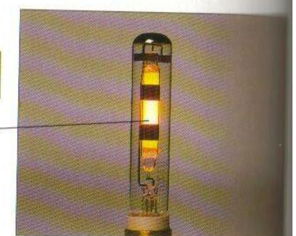


GREEN LED

Two colours of light very close together in the orange part of the spectrum are produced

Lamp appears orange

SODIUM LAMP
In a sodium lamp, an electric current excites electrons in sodium vapour, giving them extra energy. The electrons give the energy out as light.

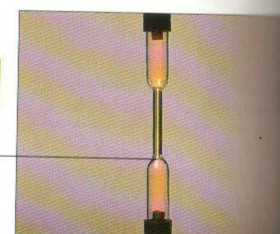


SODIUM LAMP

Only certain colours characteristic of neon are produced

Lamp appears orange

NEON TUBE
In a similar way to a sodium lamp, a neon discharge lamp produces a characteristic orange glow.



NEON TUBE

STANDARD CANDLES

Cepheid variable

Pulse $\propto$ size

Pulse rate

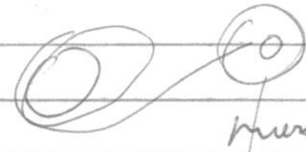
↳ size of ~~star~~ star

Look at size it appears on earth

↓

Determine distance

Type 1 Supernova



Draws matter from nearby source.

mass $\approx 1\frac{1}{2}$ Sun

↓

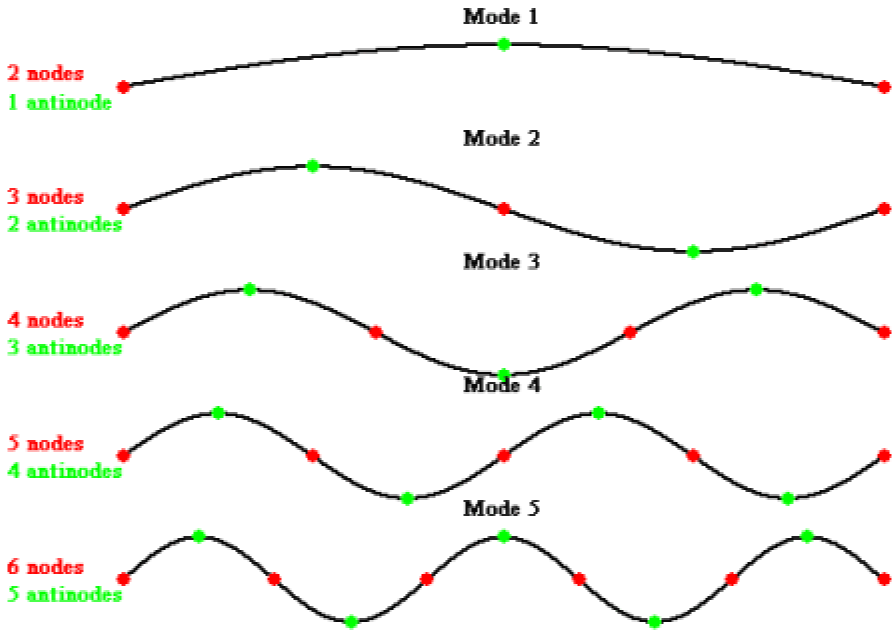
explodes

constant flash intensity

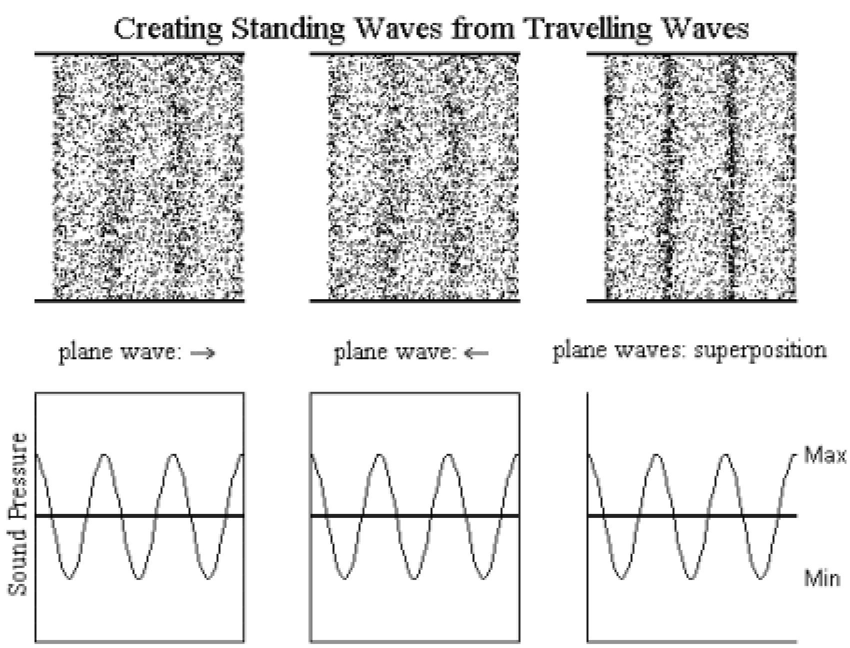
↓

determine distance

Closer objects → Parallax

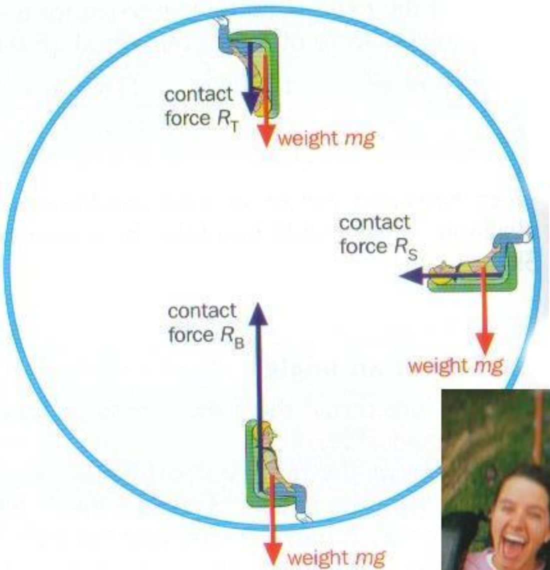

Mode 1
2 nodes
1 antinode
Mode 2
3 nodes
2 antinodes
Mode 3
4 nodes
3 antinodes
Mode 4
5 nodes
4 antinodes
Mode 5
6 nodes
5 antinodes

isvr


Creating Standing Waves from Travelling Waves
plane wave: →
plane wave: ←
plane waves: superposition
Sound Pressure
Max
Min

isvr

$$R_T + mg = \frac{m v^2}{r}$$

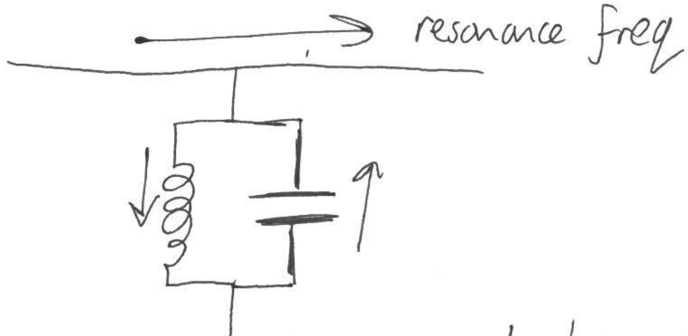


$$R_S = \frac{m v^2}{r}$$

$$R_B - mg = \frac{m v^2}{r}$$

When

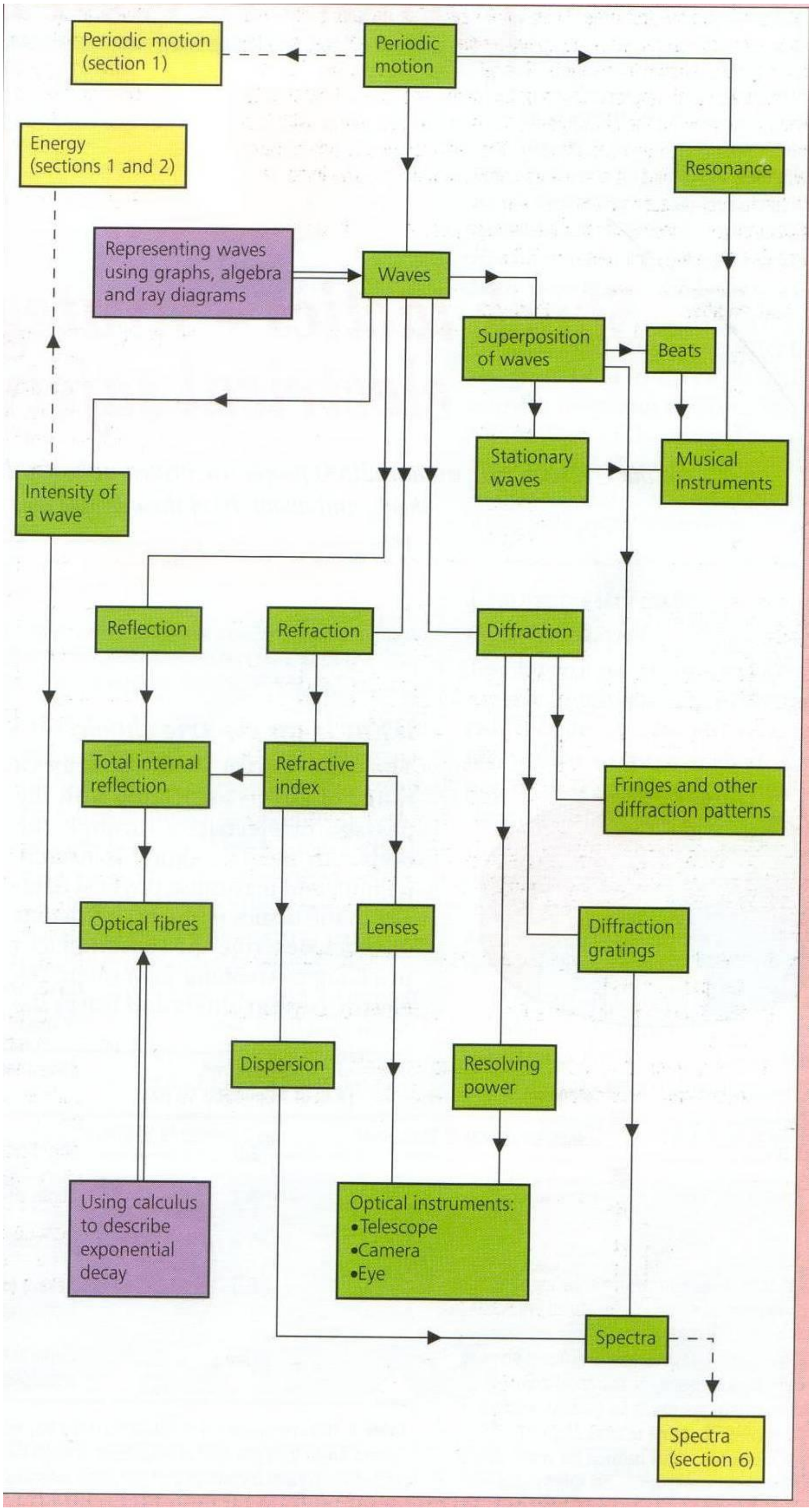
$$X_C = X_L$$



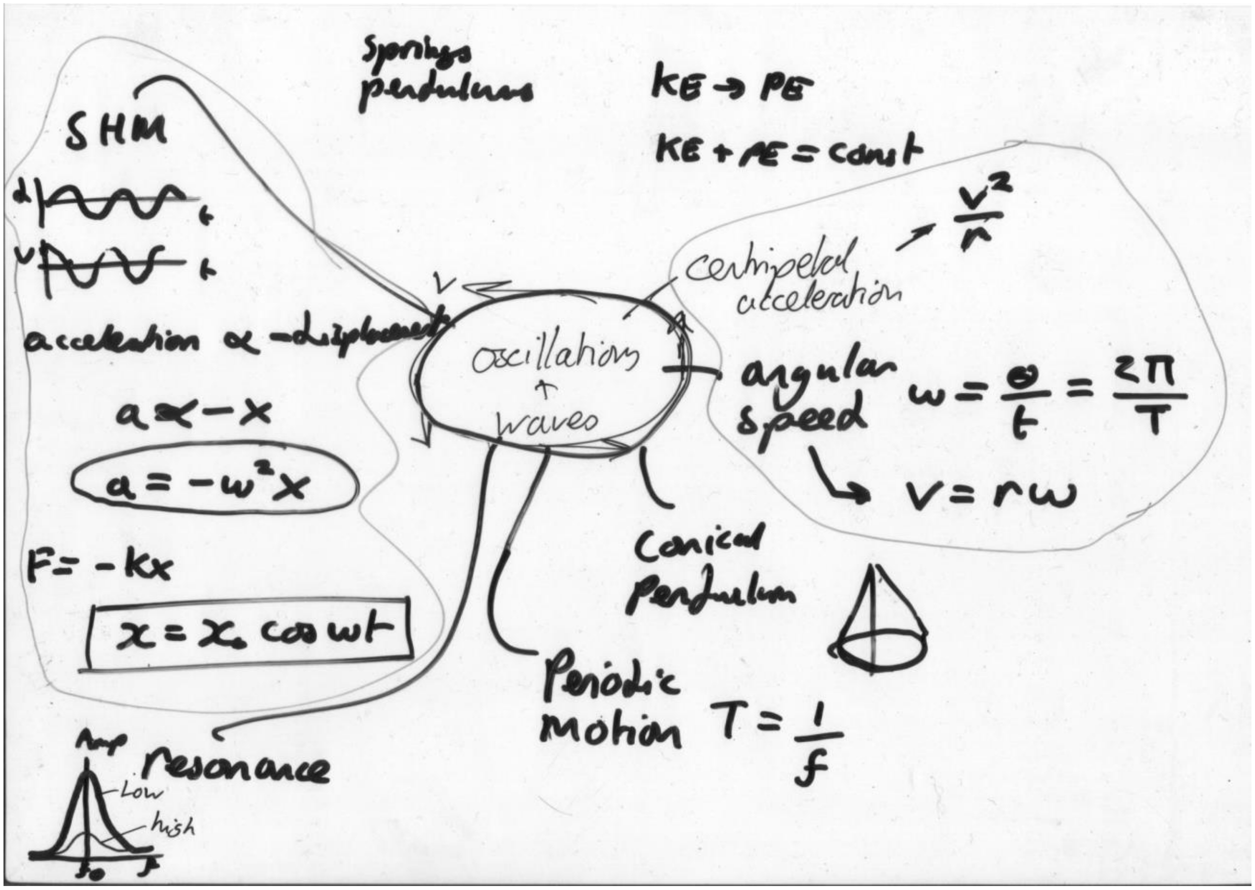
The AC resistance is the same so current does not Go to earth

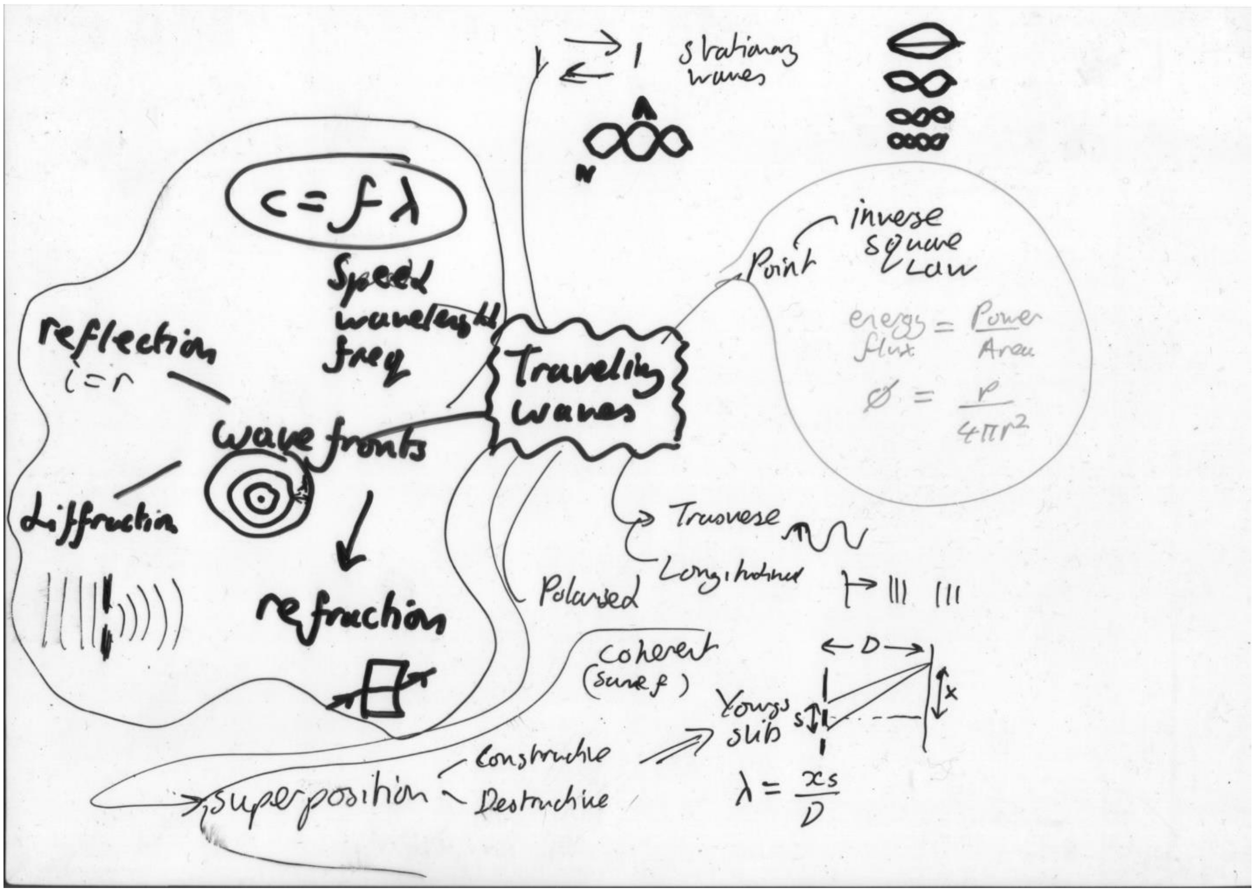
$$\frac{1}{2\pi f_0 C} = 2\pi f_0 L$$

$$f_0^2 = \frac{1}{4\pi^2 LC} \Rightarrow f_0 = \frac{1}{2\pi\sqrt{LC}}$$

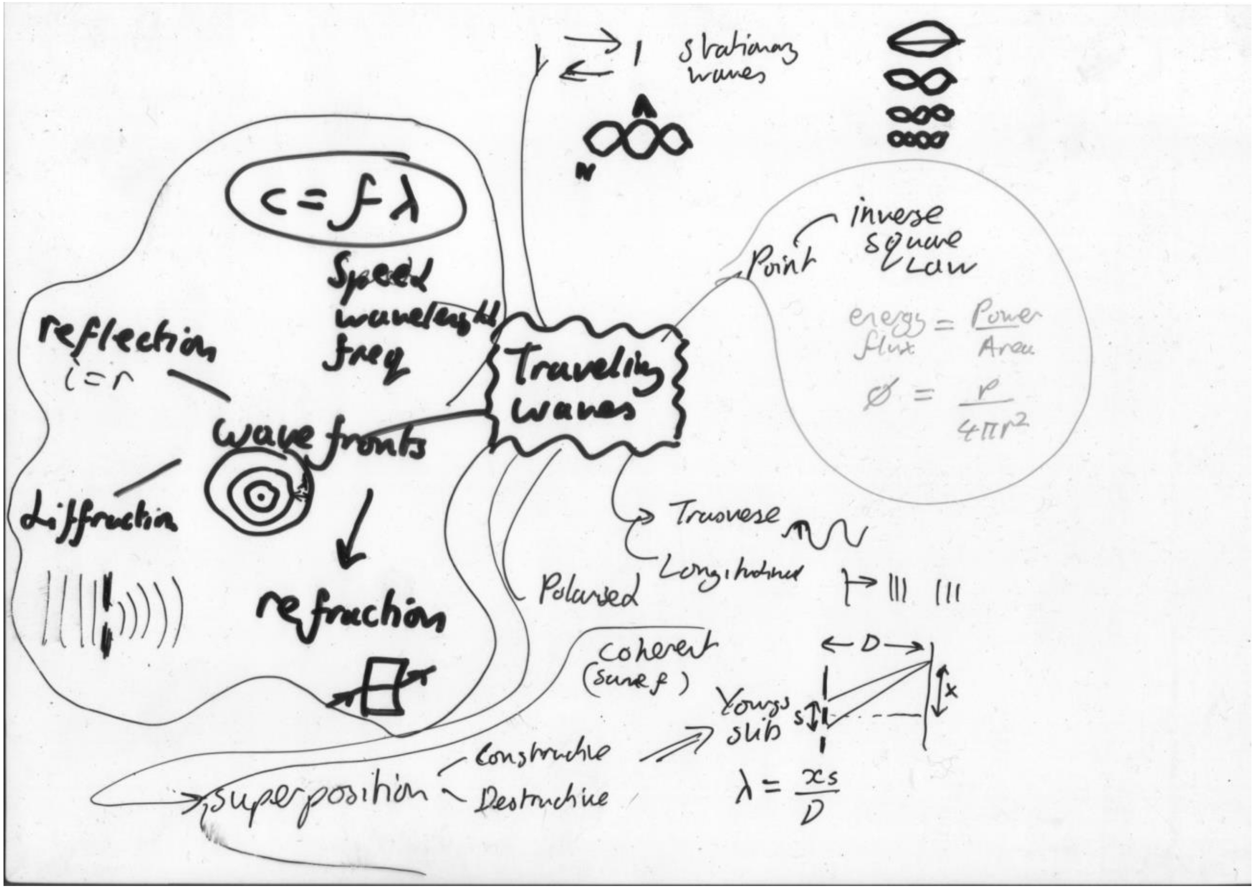


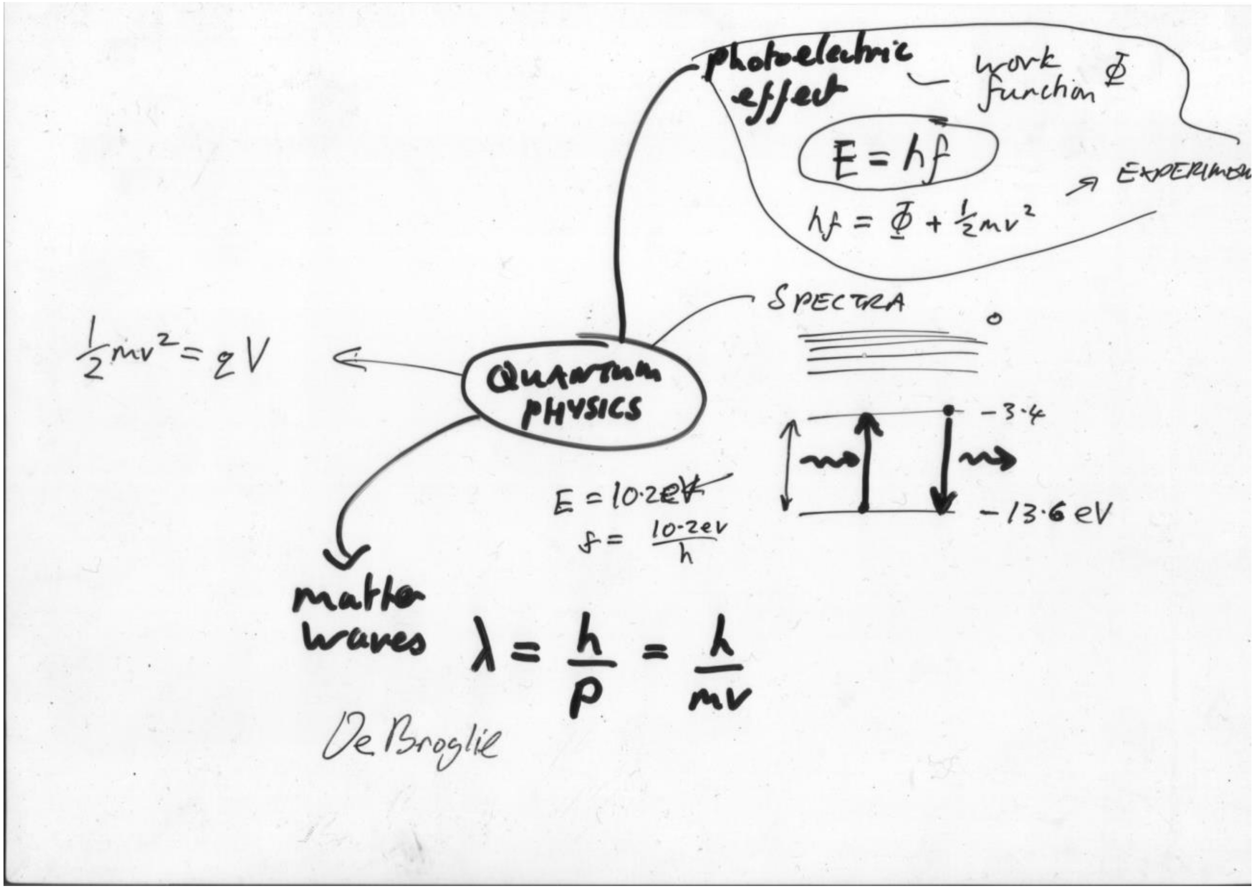
Periodic motion (section 1)
Periodic motion
Energy (sections 1 and 2)
Resonance
Representing waves using graphs, algebra and ray diagrams
Waves
Superposition of waves
Beats
Stationary waves
Musical instruments
Intensity of a wave
Reflection
Refraction
Diffraction
Total internal reflection
Refractive index
Fringes and other diffraction patterns
Optical fibres
Lenses
Diffraction gratings
Dispersion
Resolving power
Using calculus to describe exponential decay
Optical instruments:
•Telescope
•Camera
•Eye
Spectra
Spectra (section 6)


Springs
pendulums
KE → PE
KE + PE = const
SHM
d
t
v
t
acceleration ∝ −displacement
a ∝ −x
a = −w²x
F = −kx
x = x₀ cos wt
oscillations + waves
centripetal acceleration
v²/r
angular speed
w = θ/t = 2π/T
v = rw
Conical Pendulum
Periodic motion
T = 1/f
resonance
Amp
Low
high
f₀
f

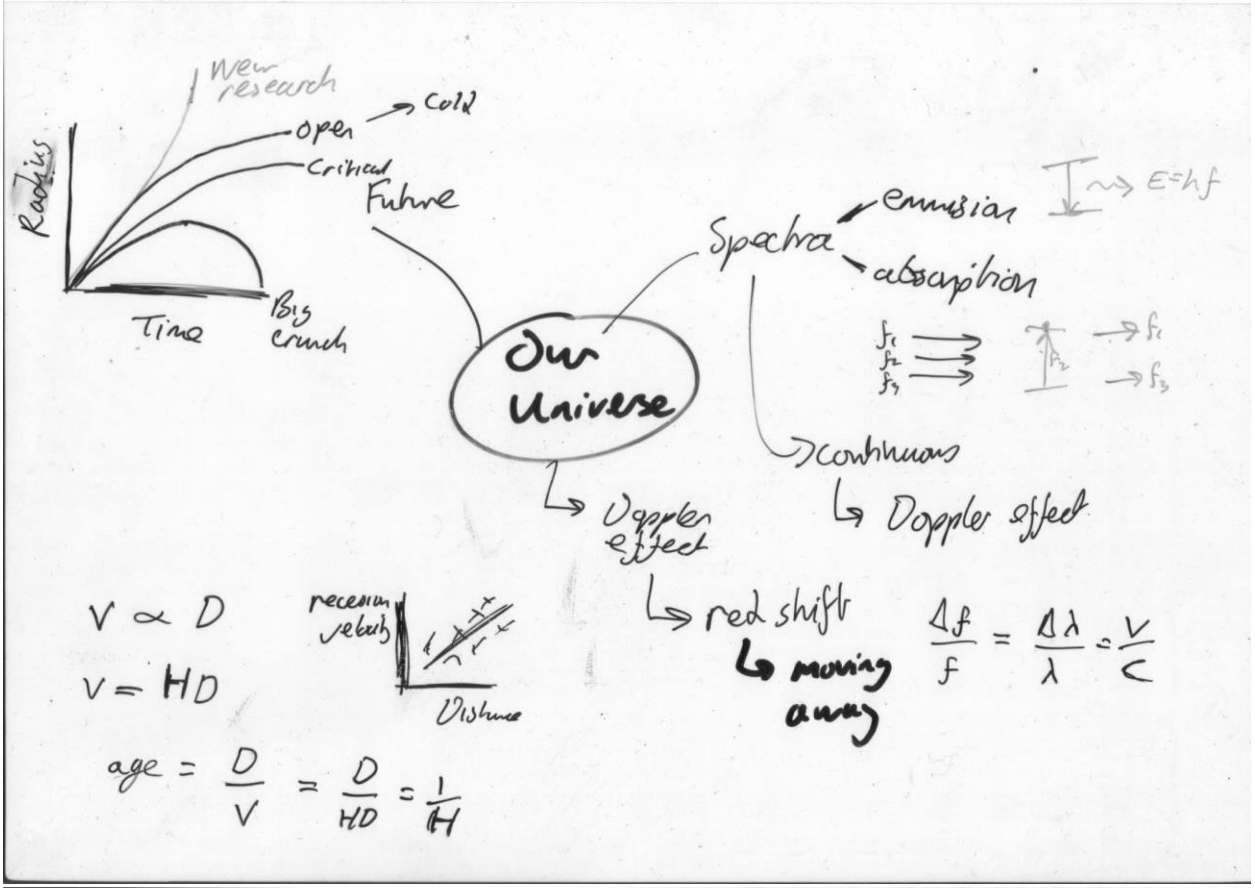


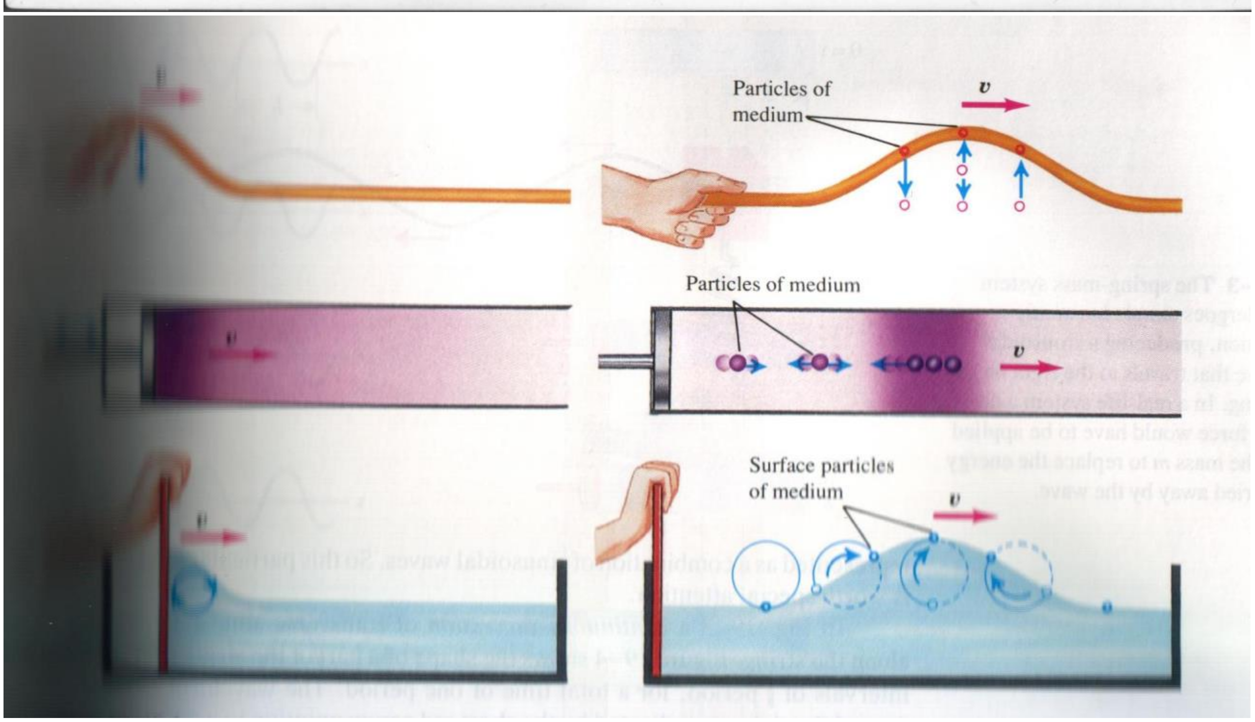
stationary waves
c=fλ
Speed
wavelength
freq
reflection
i=r
Traveling waves
wavefronts
Diffraction
refraction
Point
inverse square Law
energy flux = Power / Area
Ø = P / 4πr²
Transverse
Longitudinal
Polarised
coherent
(same f)
Youngs slits
D
s
x
λ = xs / D
Constructive
superposition
Destructive

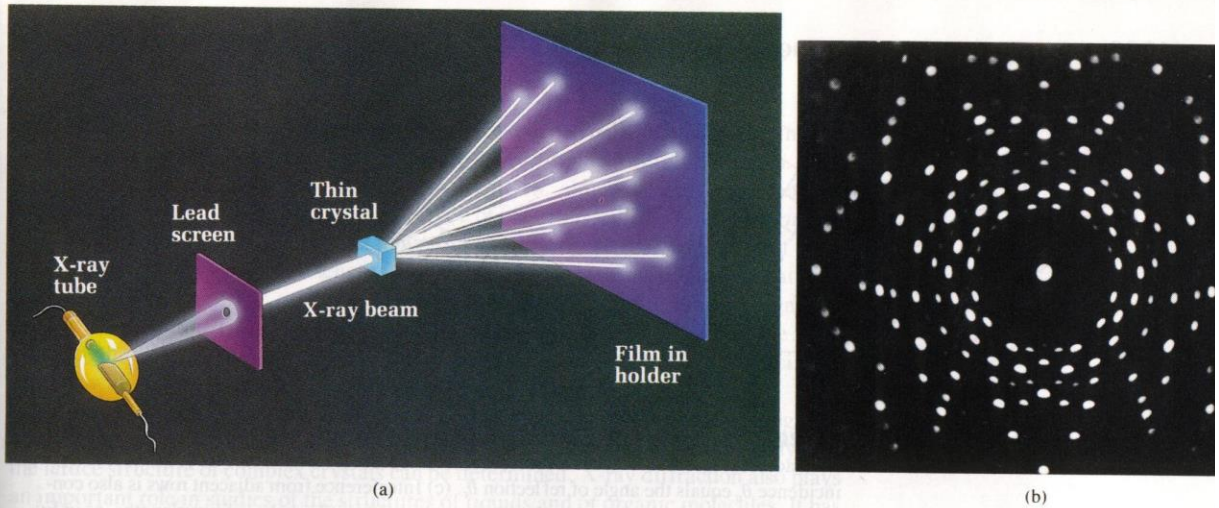

Stationary waves
c = fλ
Speed
wavelength
freq
reflection
i = r
wave fronts
Diffraction
refraction
Traveling waves
Point
inverse square law
energy flux = Power / Area
Ø = P / 4πr²
Trasverse
Longitudinal
Polarised
coherent (same f)
Youngs slits
D
s
x
λ = xs / D
superposition
Constructive
Destructive



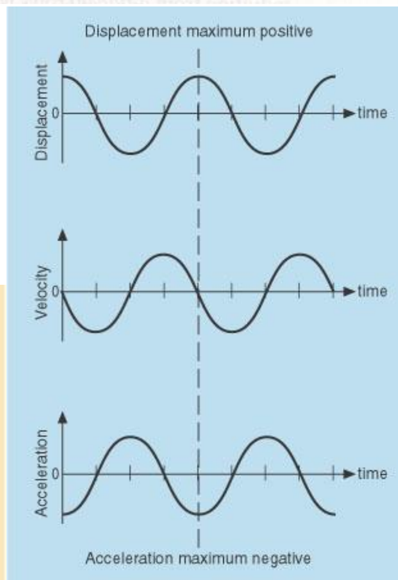
Photoelectric effect
work function Φ
E = hf
hf = Φ + ½mv²
EXPERIMEN
SPECTRA
0
-3.4
-13.6 eV
E = 10.2eV
f = 10.2ev / h
QUANTUM PHYSICS
½mv² = qV
matter waves
λ = h/p = h/mv
De Broglie

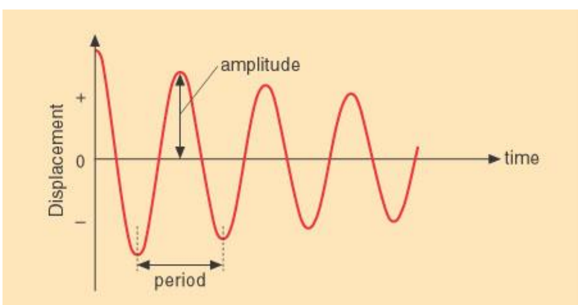

New research
Open → Cold
Critical
Radius
Time
Big crunch
Future
Our Universe
Spectra
emission
absorption
$E=hf$
f_1
f_2
f_3
f_1
f_3
continuous
Doppler effect
Doppler effect
red shift
moving away
$\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} = \frac{V}{C}$
$V \propto D$
$V = HD$
recession velocity
Distance
$age = \frac{D}{V} = \frac{D}{HD} = \frac{1}{H}$

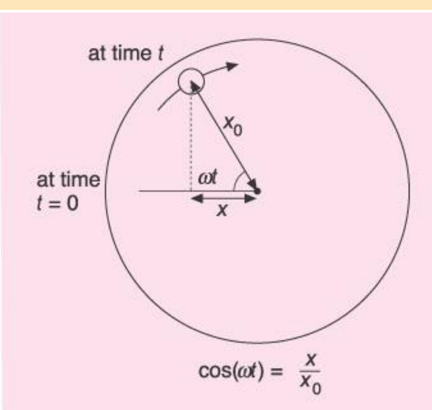

Particles of medium
v
Particles of medium
v
Surface particles of medium
v

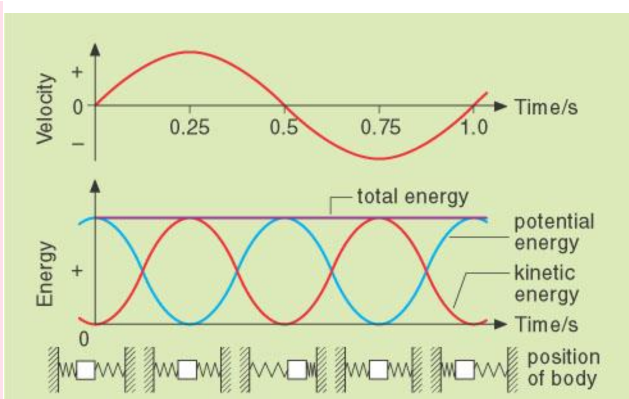


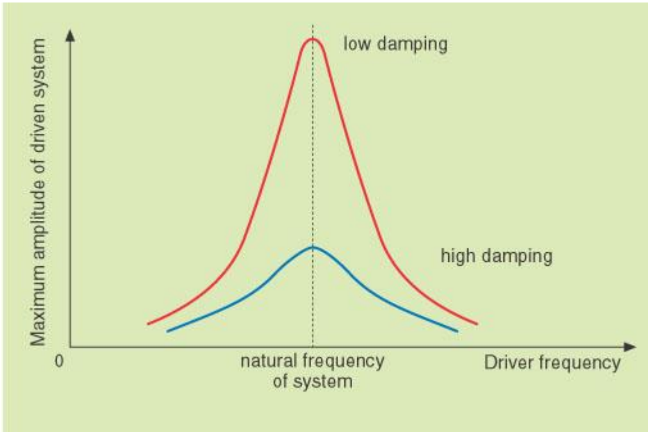
38–18 (a) In an x-ray diffraction experiment, most x rays pass straight through the crystal, but some are scattered, forming an interference pattern that exposes the film in a pattern related to the atomic arrangement in the crystal. (b) Laue diffraction pattern formed by directing a beam of x rays at a thin section of quartz crystal.





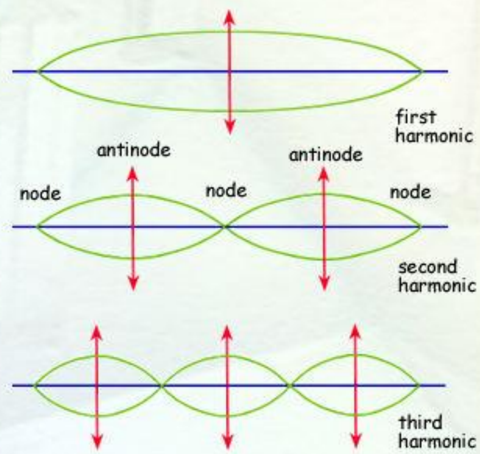






Standing Waves

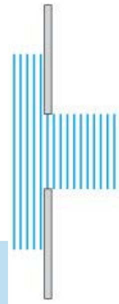
Standing or stationary waves are produced when two waves with the same frequency and amplitude move towards each other and become superimposed. The result is the creation of fixed nodal points of zero displacement which alternate with fixed antinodal points of maximum displacement. These nodes and antinodes are half a wavelength apart. Standing waves do not transfer energy along their length, as do progressive waves.



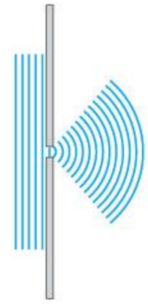
Plucking a stretched string fixed at both ends, such as one on a stringed instrument, produces a standing wave with two fixed nodes at each end. The three simplest standing waves or modes are the first, second and third harmonics.

The first harmonic (or fundamental) has a node separation of $\frac{\lambda}{2} = L$
The string length is half a wavelength.
The second harmonic (or first overtone) has a node separation of $\frac{\lambda}{2} = \frac{L}{2}$
The string length is one wavelength.
The third harmonic (or second overtone) has a node separation of $\frac{\lambda}{2} = \frac{L}{3}$
The string length is one and a half wavelengths.

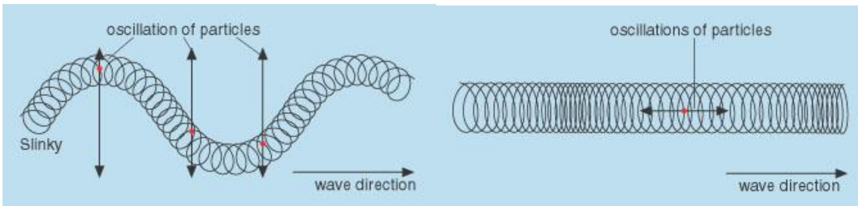
Standing waves such as the vibrations (overtones) of a stringed instrument can generate progressive waves. The progressive sound waves passing through air have the same frequency as the plucked string which generates them. The frequencies of each harmonic are whole number multiples of the lowest fundamental frequency. For a stringed instrument, when plucked, the string vibrates with all these frequencies.

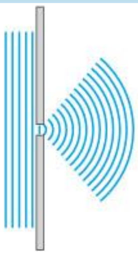


small
wavelength,
large gap

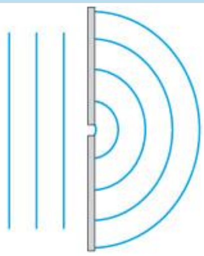


small
wavelength,
small gap

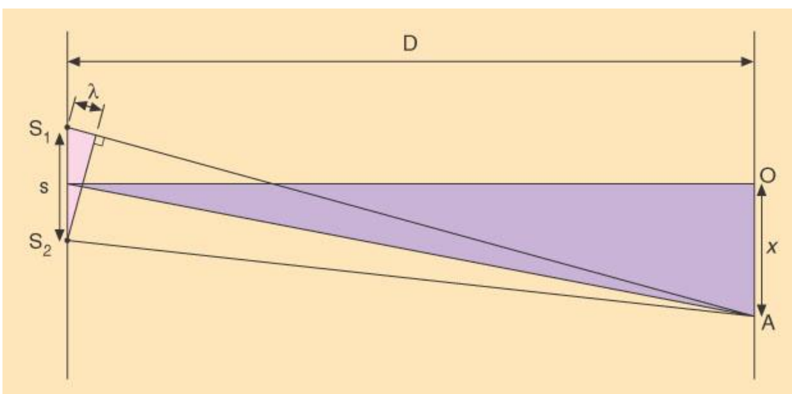


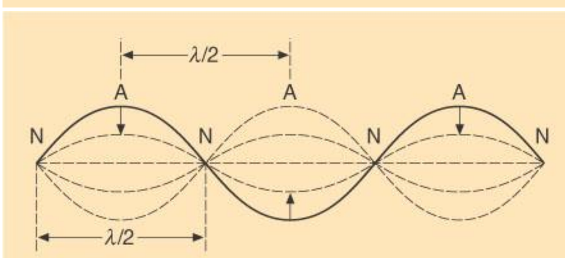


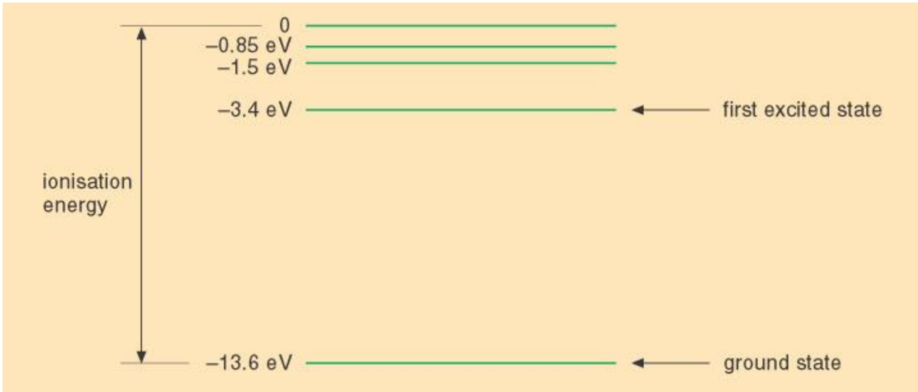
small wavelength,
small gap



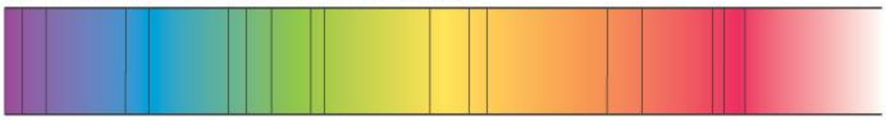
large wavelength,
small gap



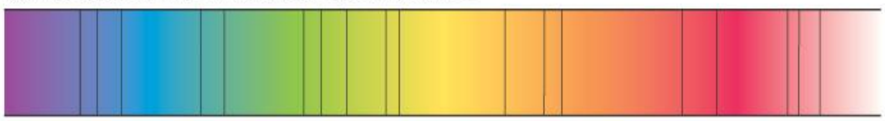


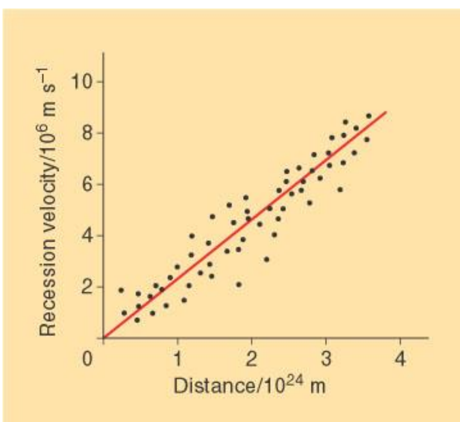


(a) Absorption bands in light from nearby galaxies

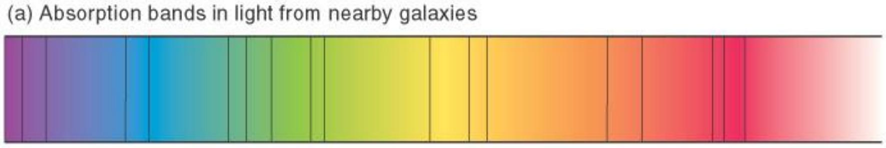


(b) Absorption bands in light from distant galaxies

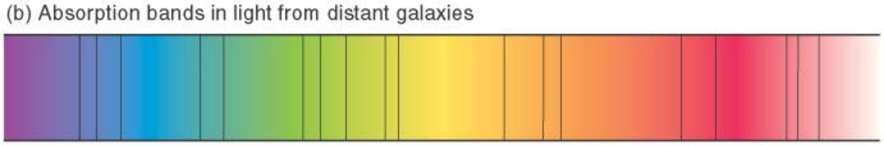


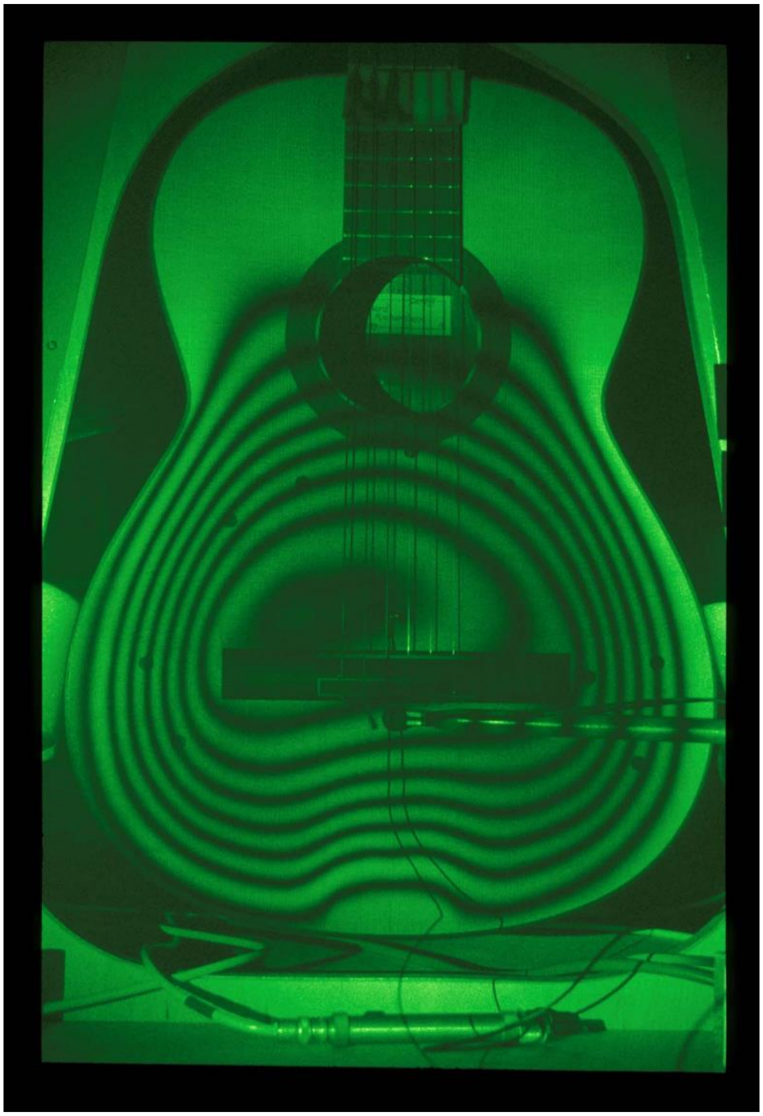


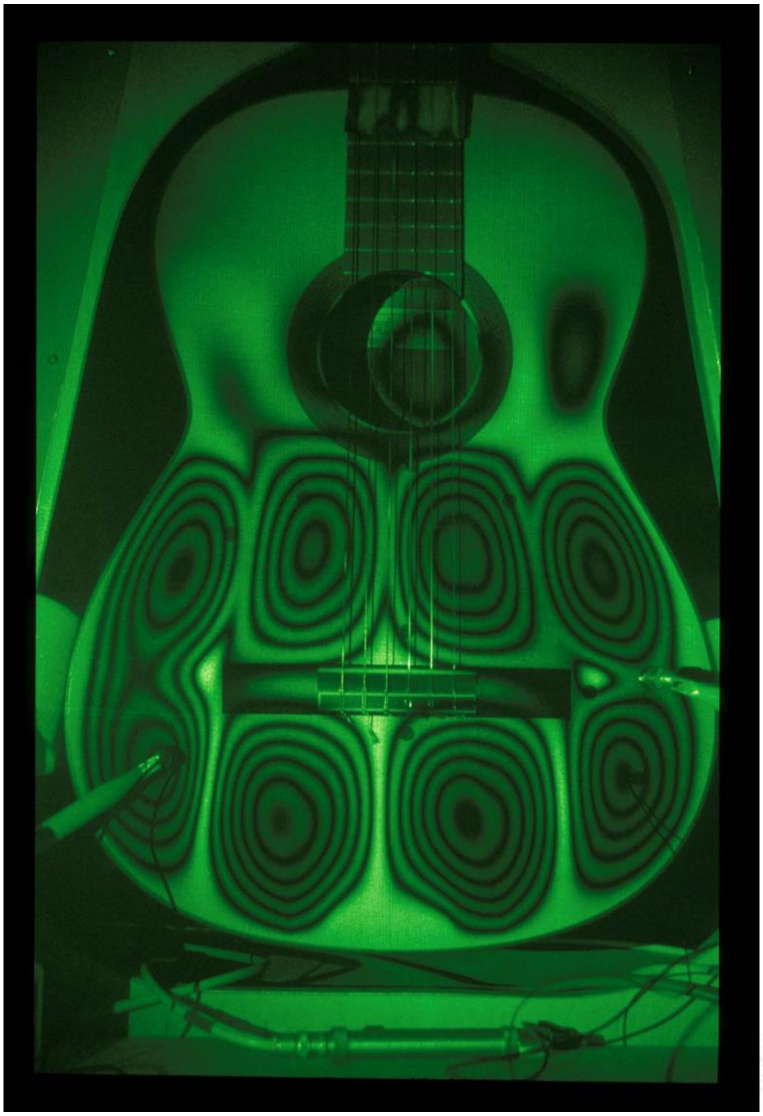
(a) Absorption bands in light from nearby galaxies



(b) Absorption bands in light from distant galaxies







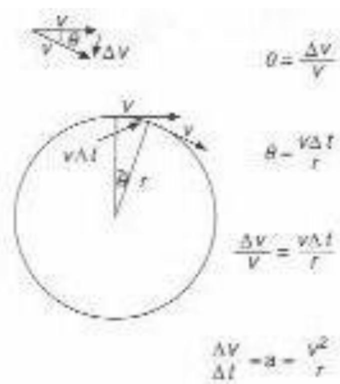
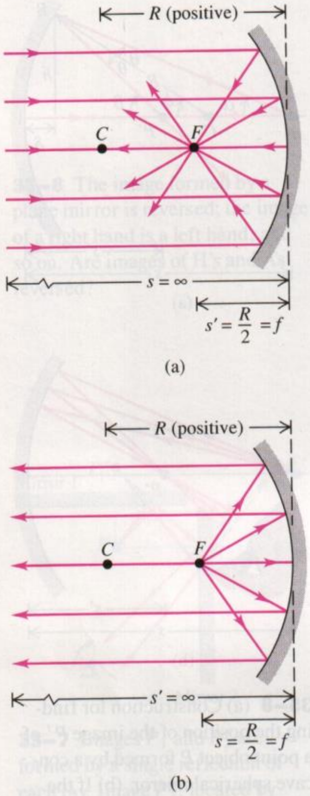


Figure 2.1 Centripetal acceleration $= \frac{v^2}{r}$



35–9 (a) Incident rays parallel to the axis converge to the focal point F of a concave mirror. (b) Rays diverging from the focal point F of a concave mirror are parallel to the axis after reflection. The angles are exaggerated for clarity.

Focal Point

When the object point P is very far from the mirror ($s = \infty$), the incoming rays are parallel. From Eq. (37–4) the image distance s' is given by

$$\frac{1}{\infty} + \frac{1}{s'} = \frac{2}{R}, \qquad s' = \frac{R}{2}.$$

The situation is shown in Fig. 35–9a. A beam of incident parallel rays converges, after reflection, to a point F at a distance $R/2$ from the vertex of the mirror. Point F is called the **focal point,** and its distance from the vertex, denoted by f, is called the **focal length.** We see that f is related to the radius of curvature R by

$$f = \frac{R}{2}.$$

We can discuss the opposite situation, shown in Fig. 35–9b. When the image distance s' is very large, the outgoing rays are parallel to the optic axis. The object distance s is then given by

$$\frac{1}{s} + \frac{1}{\infty} = \frac{2}{R}, \qquad s = \frac{R}{2}.$$

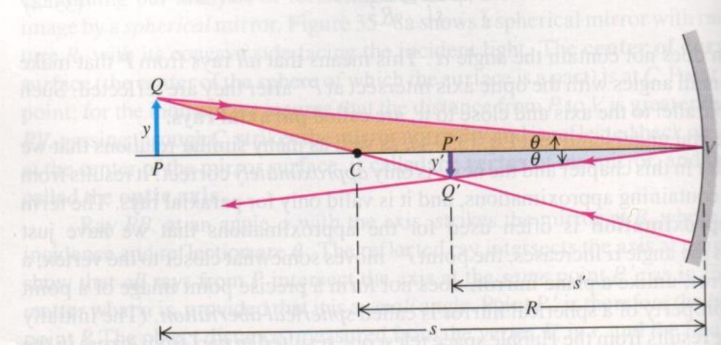
In Fig. 35–9b, rays coming to the mirror from the focal point are reflected parallel to the optic axis. Again we see that $f = R/2$.

Thus the focal point F of a concave spherical mirror has the properties that (1) any incoming ray parallel to the optic axis is reflected through the focal point and (2) any incoming ray that passes through the focal point is reflected parallel to the optic axis. For spherical mirrors these statements are true only for paraxial rays; for parabolic mirrors they are *exactly* true.

We will usually express the relationship between object and image distances for a mirror, Eq. (35–4), in terms of the focal length f:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}.$$

Now suppose we have an object with finite size, represented by the arrow PQ in Fig. 35–10, perpendicular to the axis PV. The image of P formed by paraxial rays is at P'. The object distance for point Q is very nearly equal to that for point P, so the image $P'Q'$

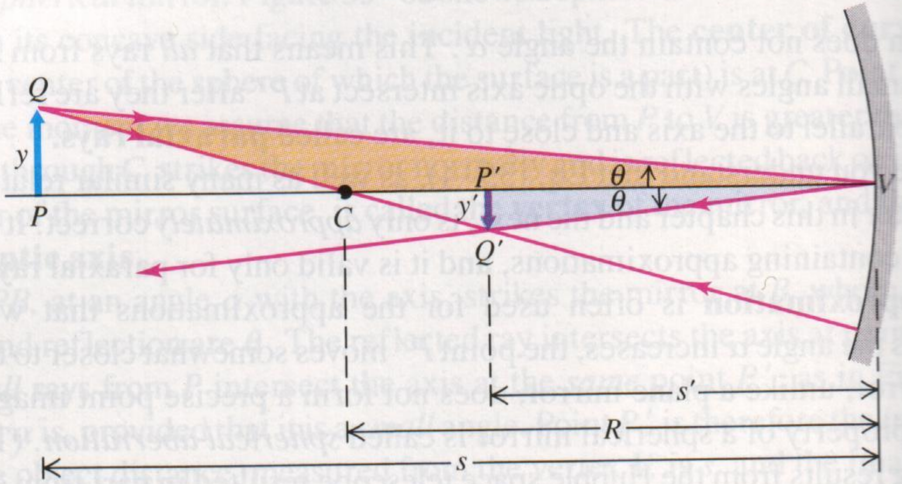


35–10 Construction for determining the position, orientation, and height of an image formed by a concave spherical mirror.

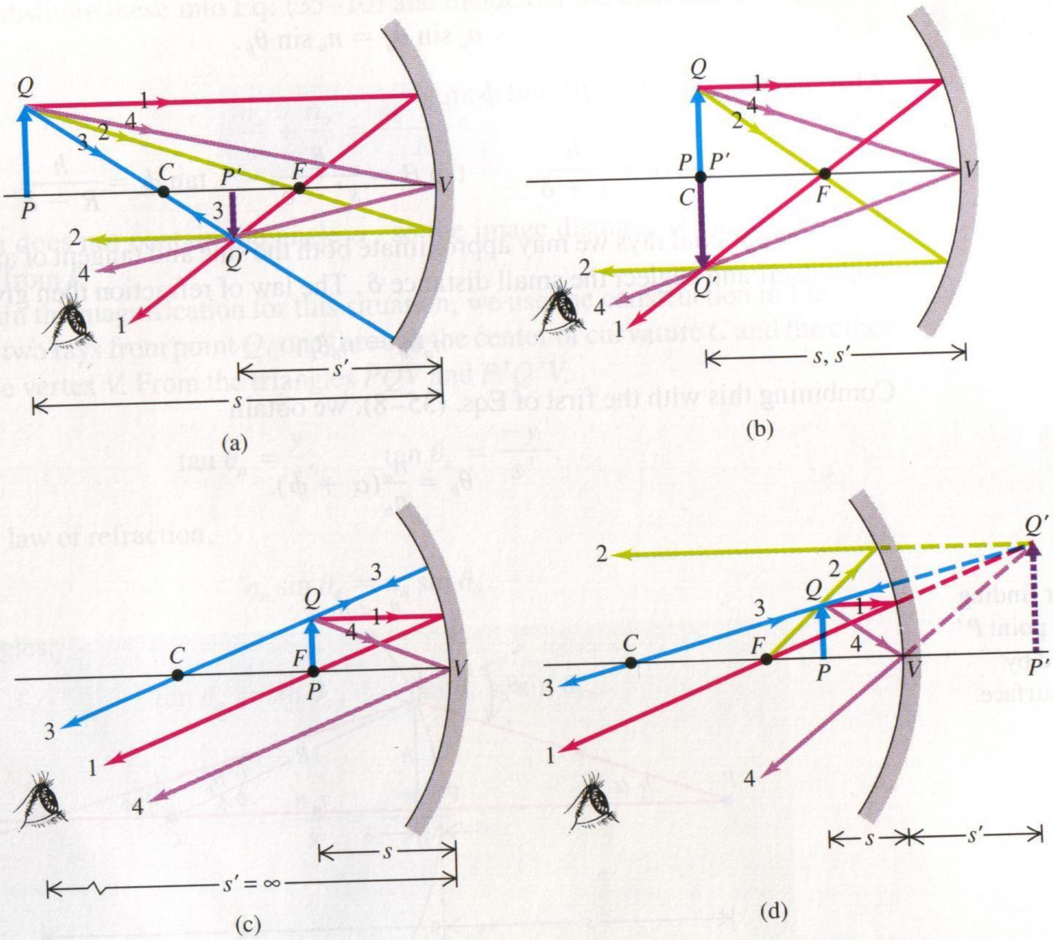
mirror, Eq. (35–4), in terms of the focal length:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}.$$

Now suppose we have an object with finite size, represented by the arrow [in] Fig. 35–10, perpendicular to the axis *PV*. The image of *P* formed by paraxial rays [...] The object distance for point *Q* is very nearly equal to that for point *P*, so the image [...]



35–10 Construction for determining the position, orientation, and height of an image [formed] by a concave spherical mirror.



35–17 Image of an object at various distances from a concave mirror, showing principal rays.

Particles as waves

de Broglie's hypothesis

> a particle with momentum p has an associated wavelength λ given by
> $$\lambda = h/p$$
> this wavelength is called the *de Broglie wavelength*

- Because h is very small, only atomic-sized particles will have sufficiently small momentum for λ to be detectable.
- If the de Broglie wavelength for an electron is comparable to atomic dimensions then *electron diffraction* effects can be observed (principle of electron microscope).
- If the de Broglie wavelength for an electron is comparable to *nuclear* dimensions (very high energy) then diffraction by the nucleus can be observed giving information on nuclear size.

Example 1

What is the de Broglie wavelength for an electron accelerated through a p.d. of 5.0 kV?
$m_e = 9.1 \times 10^{-31}$ kg

Stage 1

Apply the Law of Conservation of Energy to the accelerated motion:

Method 1

$$1/2\, mv^2 = eV$$
$$v = \sqrt{(2eV/m)}$$
$$= \sqrt{(2 \times 1.6 \times 10^{-19}\ \text{C} \times 5000\ \text{V}/9.1 \times 10^{-31}\ \text{kg})}$$
$$= 4.2 \times 10^7\ \text{m s}^{-1}$$
$$p = mv = 3.8 \times 10^{-23}\ \text{kg m s}^{-1}\ (\text{or N s})$$

Method 2

$$E_k = p^2/2m \text{ and } E_k = eV$$
$$p = \sqrt{(2meV)}$$
$$= 3.8 \times 10^{-23}\ \text{kg m s}^{-1}\ (\text{or N s})$$

Stage 2

Apply the de Broglie relation:

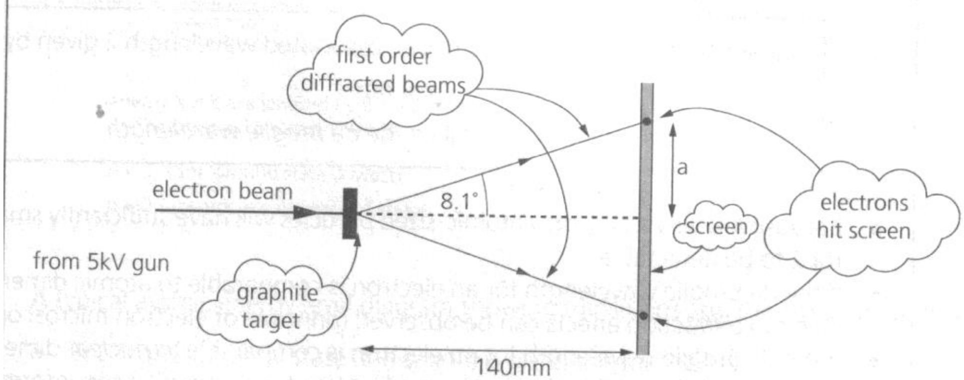
$$\lambda = h/p$$
$$= 6.6 \times 10^{-34}\ \text{J s}/3.8 \times 10^{-23}\ \text{N s}$$
$$= 1.7 \times 10^{-11}\ \text{m}$$

Example 2

The electron beam of example 1 is fired in a vacuum through a thin slice of graphite. The regularly spaced rows of carbon atoms make the crystal lattice behave like a diffraction grating to the electron beam, the diffraction following the ordinary rule for waves ($n\lambda = s \sin \theta_n$) using the de Broglie wavelength. If the atomic spacing is 1.2×10^{-10} m at what angle does the 1st order beam emerge?

> The de Broglie wavelength has already been found to be
> 1.7×10^{-11} m
> so using the grating relation
> $1 \times (1.7 \times 10^{-11} \text{ m}) = 1.2 \times 10^{-10} \text{ m} \times \sin \theta_1$
> $\theta_1 = 8.1°$

If it hits a screen 140 mm from the graphite describe what is seen on the screen.



Electron diffraction by graphite

a = 140 mm × tan 8.1° = 20 mm (2 sig.fig.)

Because the graphite sample will have many layers of atoms at all possible orientations (polycrystalline) there will be many diffracted beams at the angle 8.1°, forming an emerging cone of electrons. They hit the screen making a circle of radius 20 mm.

Wave-particle duality

This dual nature of matter and radiation – some phenomena best described on a wave basis using ideas of interference, diffraction and wavelength and others on a particle basis using momentum and kinetic energy – is called *wave-particle duality.* It forms the basis of Quantum Mechanics, the form of physical laws best suited to describe atomic and nuclear phenomena.

The wave nature of a moving particle can be applied to the electron in a hydrogen atom, where the electron is represented as a standing wave whose wavelength in the fundamental mode is twice the atom's diameter. This model, where the electron wave is thought of as representing the probability of finding an electron at particular distances, is remarkably successful at predicting the energy levels in hydrogen.