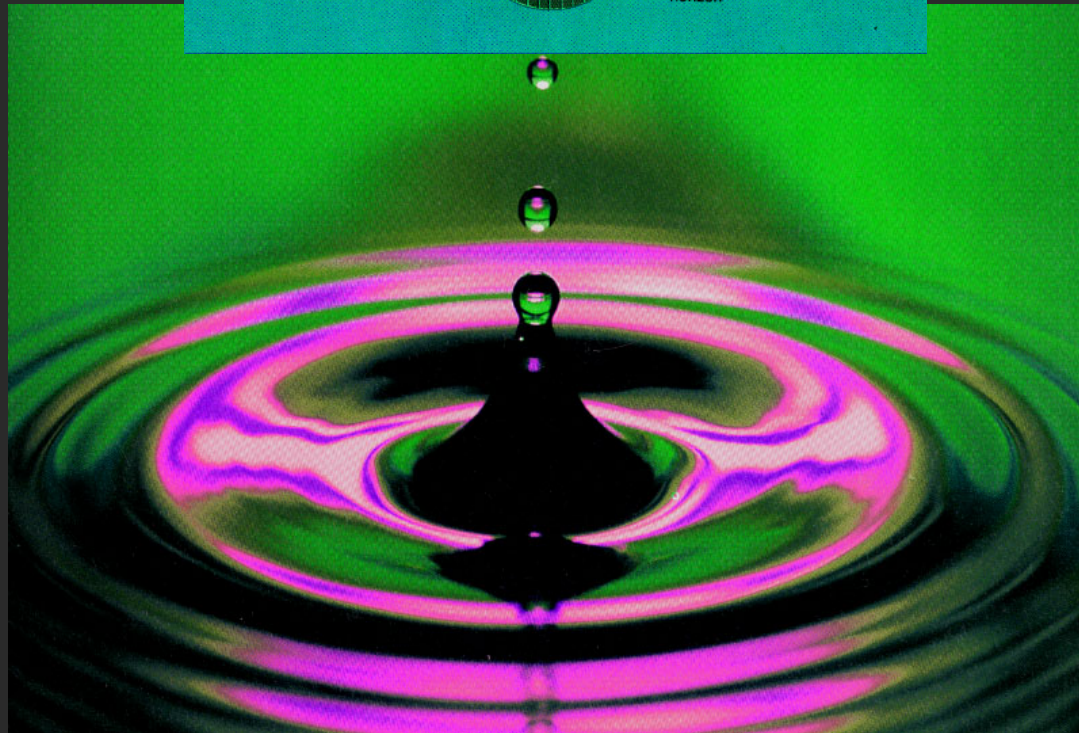
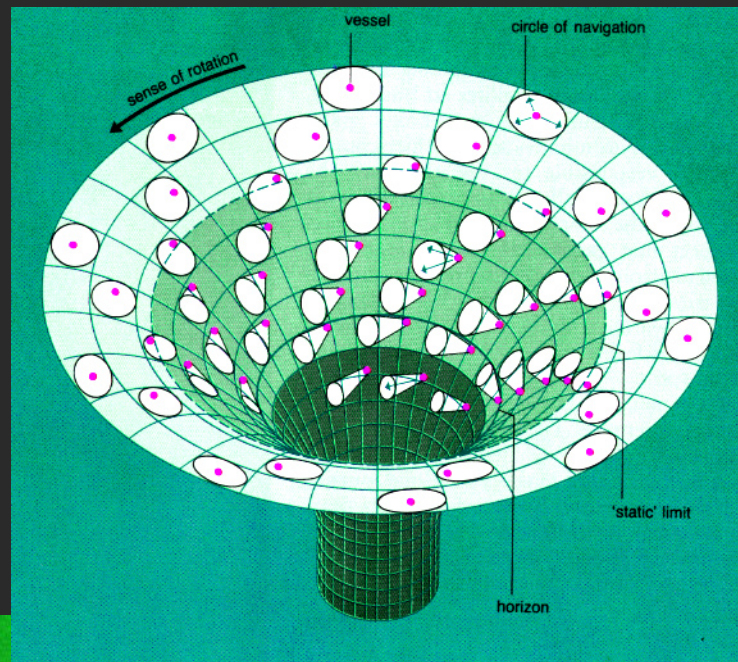


WAVES, FIELDS & SPACETIME

from
HUYGHENS
to
EINSTEIN



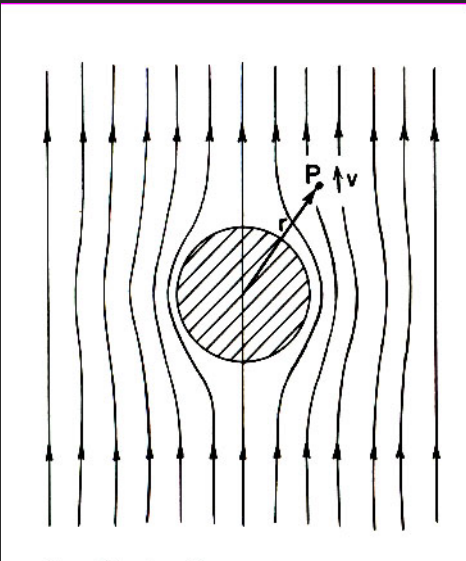
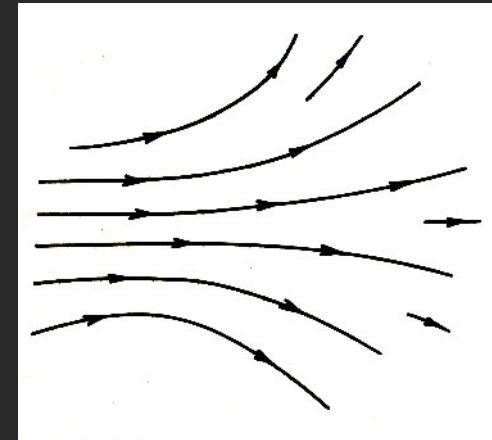
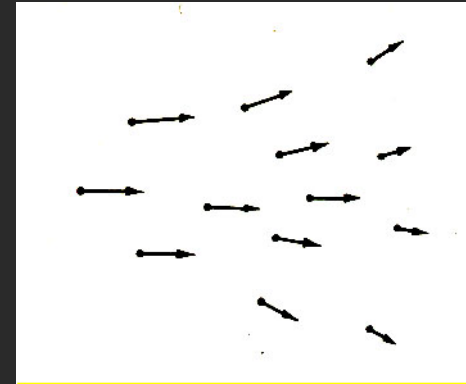
VECTOR FIELDS

This is a simplified intro to the idea of a continuous field. We

start with a **VECTOR** field. Imagine some space (eg., a 2-dimensional space as shown in the pictures). Suppose now that at each point in the space there is “something” that has a magnitude and a direction (ie., it is a vector). Let’s note immediately 2 examples:

- (i) the **FORCE** field existing in space caused by, eg., some nearby masses- remember that force is a vector.
- (ii) the **VELOCITY** field of a fluid going past a round obstacle (see below).

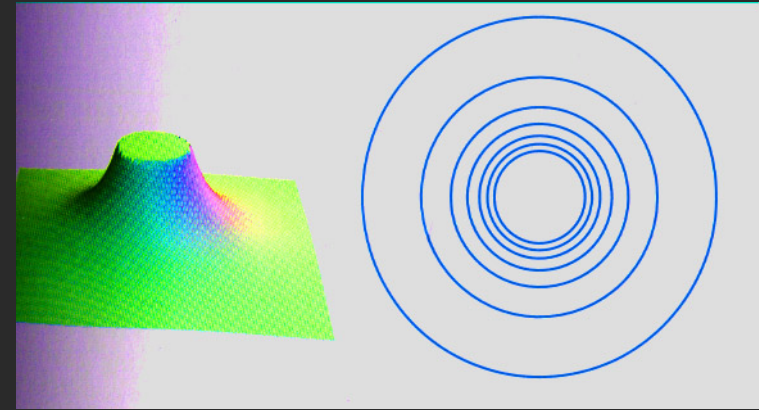
The figure at top right shows what you would get if you measured the vector field at a few select points- the vectors are represented by arrows placed at these points.



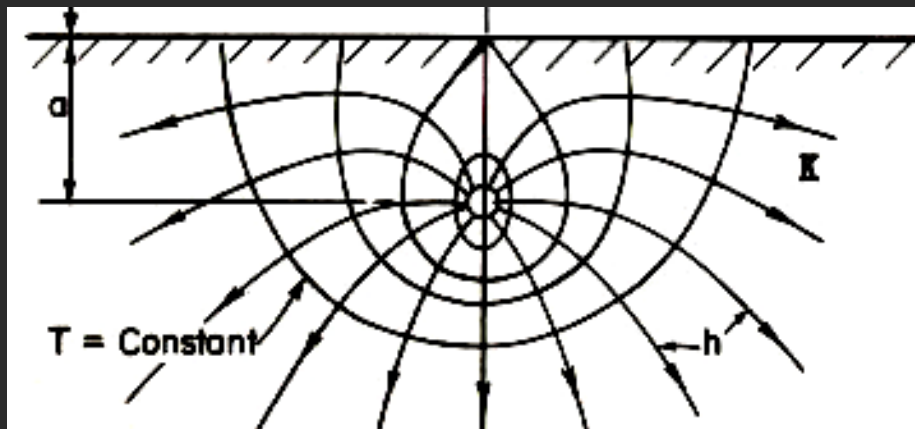
The other 2 pictures show “field lines”. You can get an idea of what these are by imagining that in the fluid flow at left, one puts a “test particle” down in the fluid at some point. We then trace out the path followed by the particle as it follows the fluid, to get one of the field lines (in fluids, these are often called ‘streamlines’). You can imagine doing the same thing with a “test mass” in a gravity field.

POTENTIAL (Scalar) FIELDS

We can also define another kind of field called a SCALAR field, in which one has a scalar (this is a fancy word meaning a NUMBER) at each point (instead of a vector). You will all be familiar with examples of these. At right we show a flat-topped hill- if we make a map of the height (a number) at every point, then we have a scalar field. If we now join up all points having the same value of the scalar, we get a CONTOUR MAP- which is also shown for the flat-topped hill.

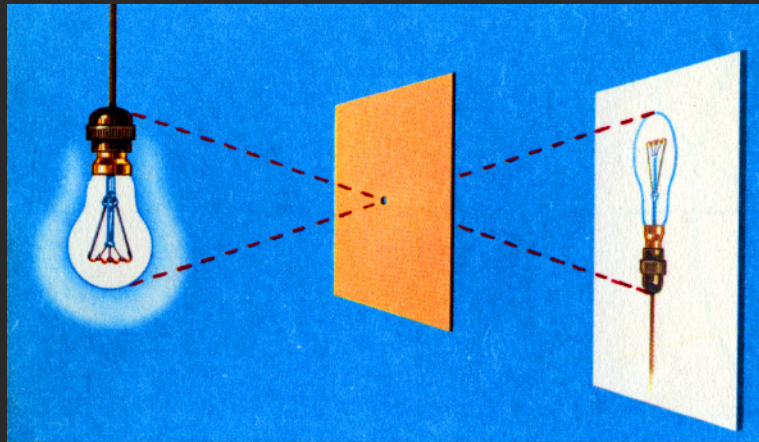
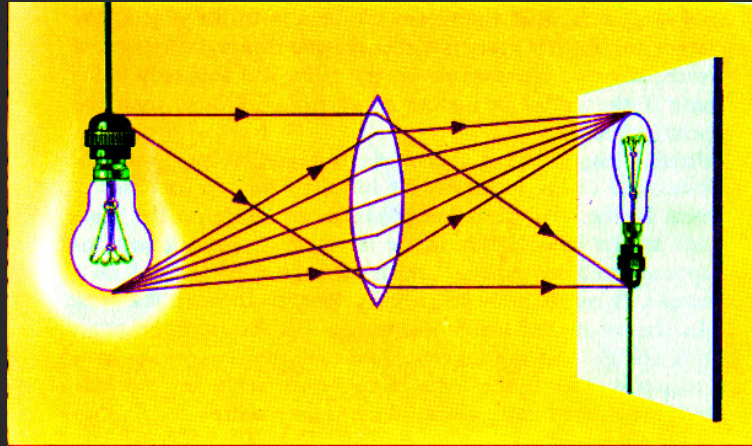


Below we see another example- it shows a plate with its boundary running along the top, and a point heat source a distance a below the boundary. Surrounding the heat source we see contours of constant temperature (labelled by $T = \text{const}$). However we also plot some 'streamlines' showing the flow of an associated



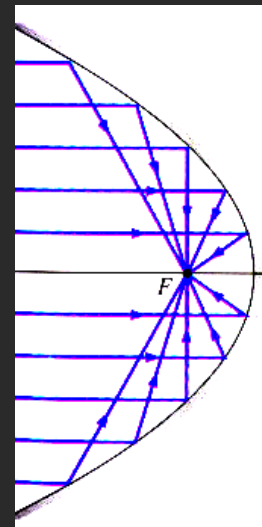
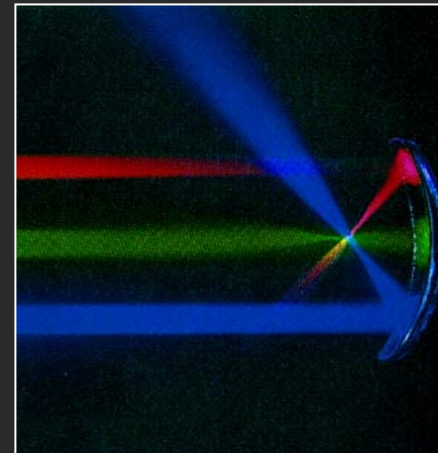
vector field, which is actually the flow of HEAT (labelled by \mathbf{K}). The heat always flows by the shortest path from high to low T , which is why the heat flow streamlines are everywhere perpendicular to the temperature contours.

The CORPUSCULAR (Particle) THEORY of LIGHT



In common with most thinkers in his day, Newton thought that light was a motion of particles (light corpuscles) in straight lines. This made a lot of sense- it seemed to be in accord with Newton's laws (refraction being explained by forces acting on boundaries between different different media), and explained image formation by lenses or pinholes. In the same way one could understand reflected light beams, mirrors, etc. The dependence of refraction on colour was explained by assuming the force acting at interfaces depends on colour.

In the top figure we see the formation of an image by a lens- the paths of different light rays from a given point of the light bulb all focus to the same point on the screen if (i) the lens has the right shape, and (ii) the screen is at the right distance. The pinhole (below) forms an image at any distance.

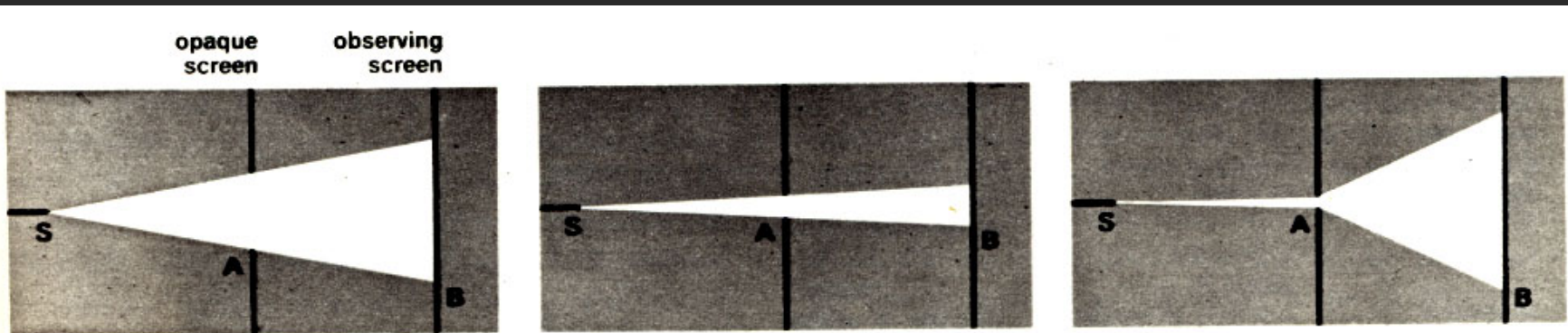
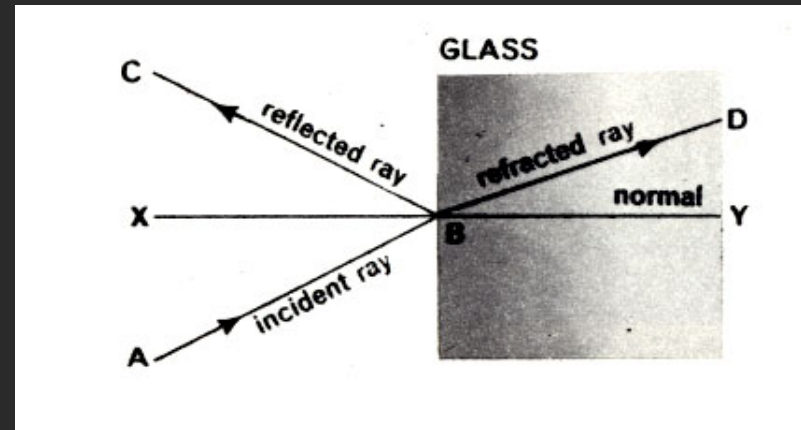


PROBLEMS with the PARTICLE THEORY of LIGHT

In spite of the virtues of the particle theory of light, careful thinkers like Huyghens realised that there were weaknesses that could not be dismissed. For example

- (i) at an interface, one never has refraction OR reflection- both happen, with the relative intensities of the 2 components depending on the angle of incidence.
- (ii) if one makes a pinhole very small, the image of the light going through begins to widen.

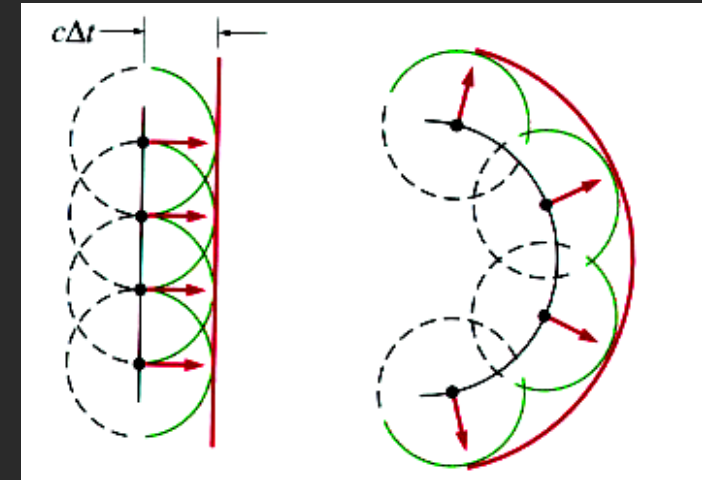
The problem of simultaneous reflection and refraction is very hard to answer- Newton's attempts were not satisfactory.



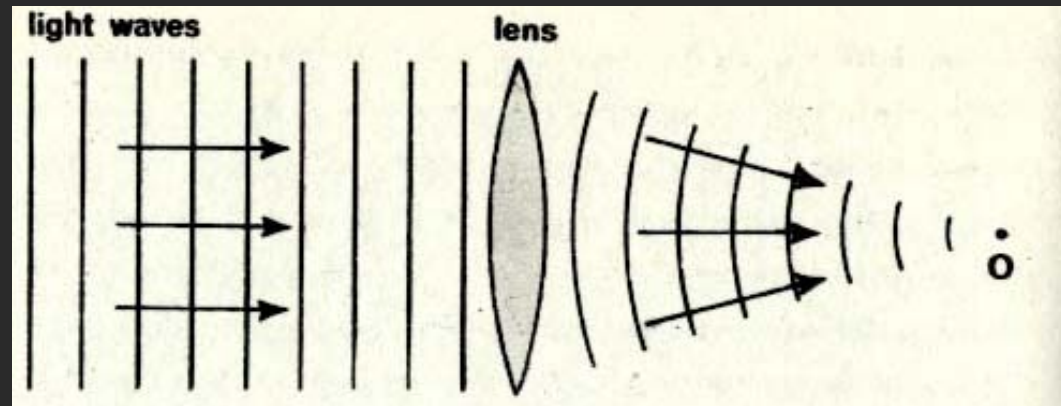
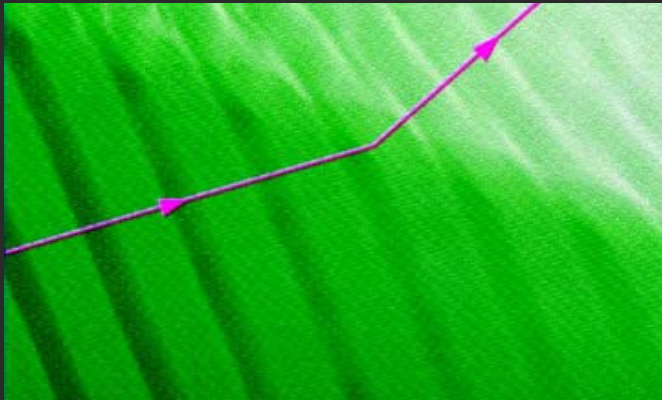
The WAVE THEORY of LIGHT

I. Waves, wavelets, & Refraction

In work that was ahead of its time, C. Huyghens succeeded in explaining all of the known properties of light propagation assuming light was a wave travelling in an unknown medium. His famous construction (right) showed how a wave front would propagate. By assuming that the waves travelled at different speeds in different media, refraction was explained- indeed, he showed how to calculate the best form for a lens in a telescope (assuming that light travelled at some slower velocity in glass than in air).



The explanation of simultaneous refraction/reflection can also be given- but came later, after the mathematical theory of waves was better developed.

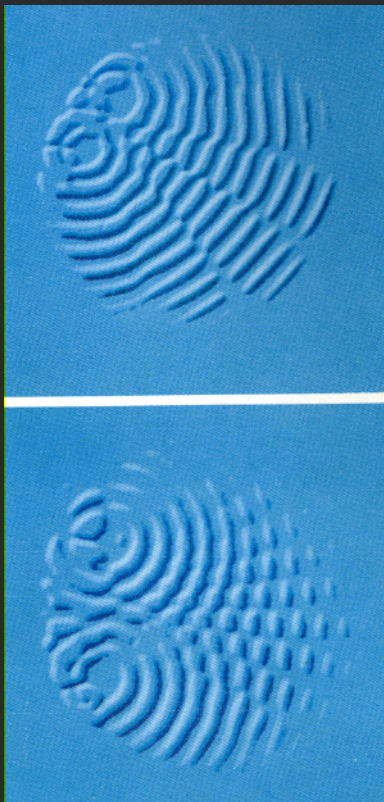
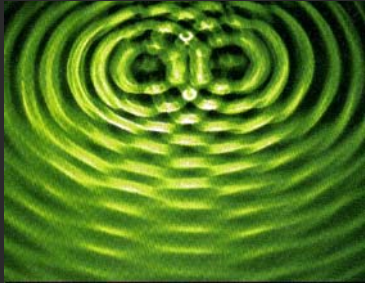


WAVE THEORY of LIGHT

II. Diffraction & Interference

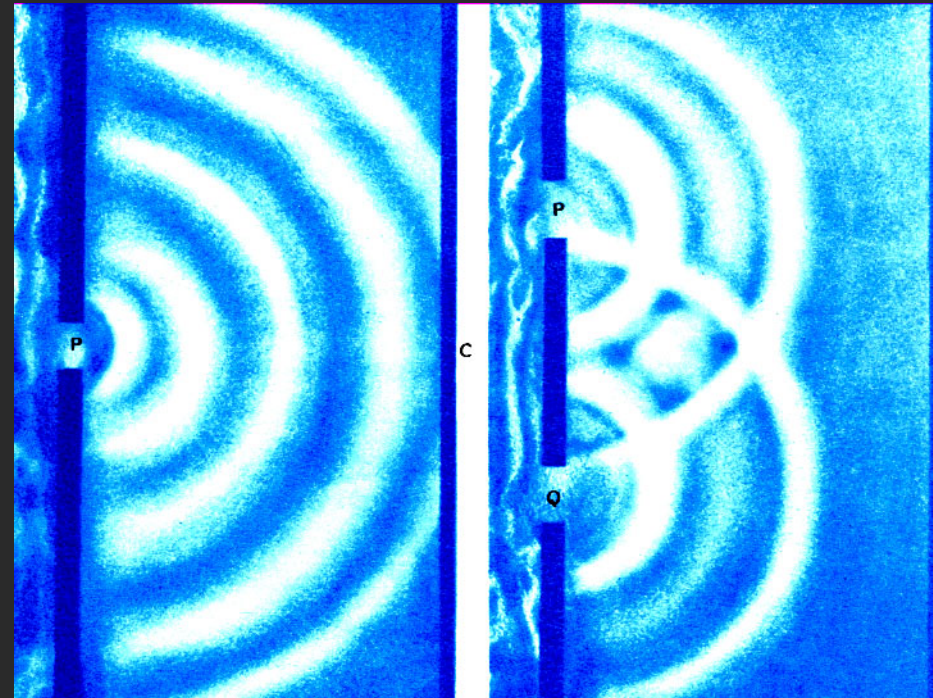
Something that can be naturally explained in a wave theory is

diffraction and interference- this was a clear prediction for light that was finally confirmed by Th. Young in 1801. One sees in the pictures how water waves passing through a pair of slits are “re-emitted” in the way shown by Huyghens, as though they were being emitted from 2 point sources. The key feature is the constructive interference between the 2 resulting wavefronts in certain directions, & the destructive interference in others.



LEFT: emission of water waves from 2 point sources- the lower waves have shorter wavelength.

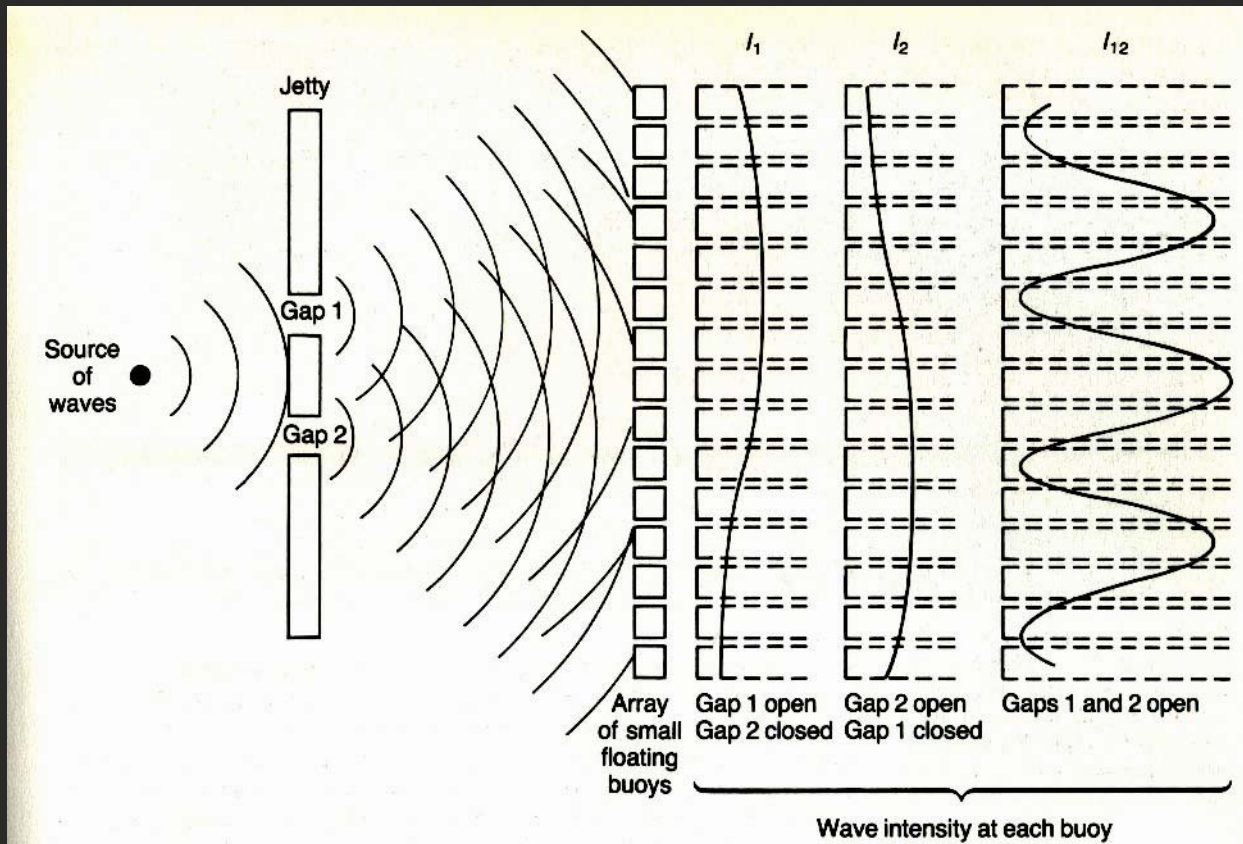
RIGHT: Diffraction of wavefront through a single slit (top), and through a pair of slits (bottom).



WAVE THEORY of LIGHT

III: 2-slit interference

The key feature of the 2-slit experiment with waves is shown here. If only one of the 2 slits is open, the intensity of the waves, on a screen behind the slits, will vary smoothly across the screen (with water waves the intensity can be measured by looking at the amplitude of the wave oscillations at different points along the screen). If however both slits are open, the resulting intensity is NOT the sum of that from each slit.

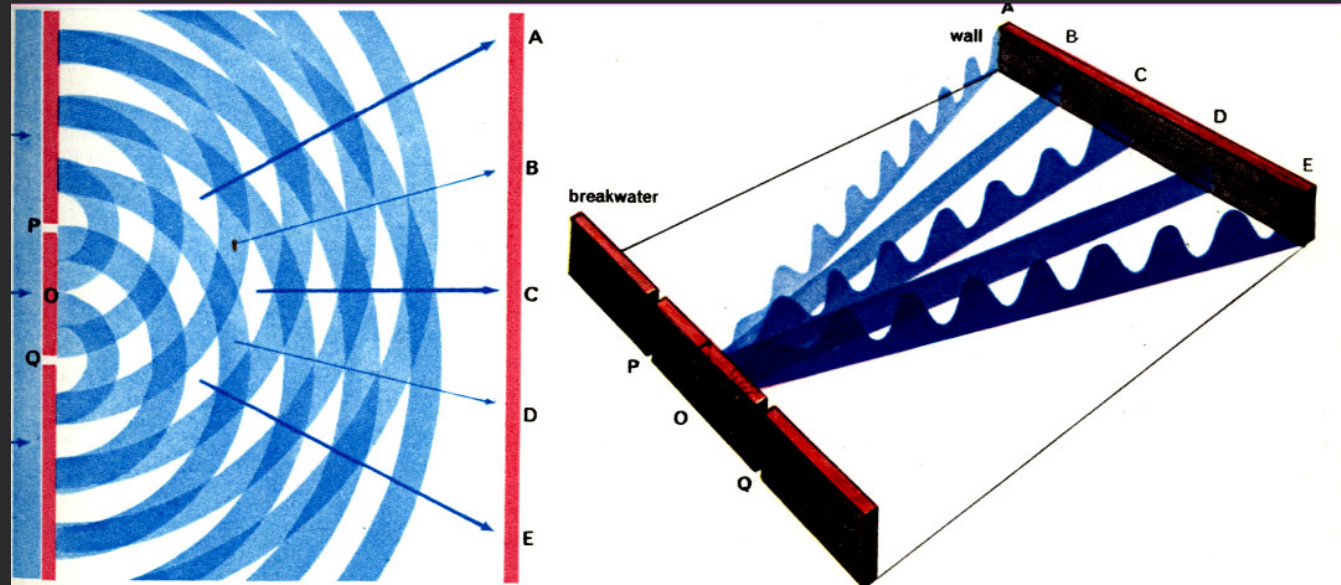


To see that this contradicts Newton's idea that light propagates as a particle, consider what would happen if particles were being emitted from the 2 slits. If the pattern of arrivals of these is as shown for each single slit, then the pattern of arrivals when both are open must be the sum of the 2 patterns for the single slits- there would be no interference.

continued....

At near right we see wave crests coming from 2 slits (diffraction sources), & how they add in certain directions.

At far right the waves propagate to the screen. In the directions between constructive interference, troughs from one slit meet crests from the other, & cancel.



A change in wavelength changes the distance between maxima of intensity on the screen- eg., halving the wavelength will halve the distance between maxima.

This is clearly seen with light of different colours- interference experiments show that these are simply waves of different wavelength. If we accept that these travel at the same velocity (which they must, otherwise the colour of an object would change with the length of the light path), then the difference in wavelength must also correspond to a difference in the FREQUENCY, ie., the number of wavecrests passing a point every second.

