Optics Revision: Waves, Interference and Diffraction

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First, a video (hopefully!)

Welcome back! We start today with a video which we didn't get to see last time due to a technical hitch making us run out of time; it should show a low friction case.
Meanwhile I shall collect your Easter vacation homework (the harder Newton's laws problems and estimation examples).

REMINDER: Office Hours are Tuesday (tonight) 3.45–5.0 p.m. in Room 20A (the science office).

Lesson Objectives

1. To know the syllabus requirements for the waves, interference and diffraction topics.
2. To look at these topics again (revision); hopefully building understanding and seeing connexions in new ways.
3. To highlight any gaps in your knowledge which you need to plug before 6 June!

Waves

What the specification requires...

Progressive waves—Oscillation of the particles in the medium; amplitude frequency; wavelength; speed; phase; path difference. $c = f\lambda$.

Longitudinal and transverse waves—Characteristics and examples, including sound and electromagnetic waves. Polarization as evidence for transeverse waves; applications e.g. Polaroid sunglasses, aerial alignment for transmitter and receiver.

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Concept question

How far does a beam of light move in 1 ns?

1. 1 cm
2. 1 inch
3. 1 foot
4. 1 m
5. 1 mile

Superposition

The formation of stationary waves by two waves of the same frequency travelling in opposite directions. . .

Simple graphical representation of stationary waves, nodes and antinodes on strings.

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Light from a sodium lamp is emitted as a result of energy changes in the atoms, occuring in bursts lasting about 10^{-8} s. These waves are emitted randomly and rapidly, and so are out of phase with each other. Thus such a lamp is an incoherent source, due to the continual change of phase.
What, then, is a coherent source? [NB This is why Grimaldi failed with 2 slits in 1665!]

(Answer to question posed): A coherent source is one which emits light waves of the same frequency which are always in phase or which have a constant phase relationship. These can then go on to interfere constructively or destructively, i.e. they can be added together using superposition to give a brighter light (constructive), or two or more waves can partly or fully subtract from one another (cancel out) giving a dimmer light (destrucitve) than would be obtained from incoherent sources of equal brightness.

You also need to know about lasers as coherent monochromatic sources, and about safety issues but not physics issues (GROAN!)

Concept question

A planar wave is incident on a pair of slits (Young's slits), and an interference pattern results. What is seen on a screen behind the slits?

1. two spots, one behind each slit.
2. only one spot, behind the center of the pair of slits.
3. many spots distributed randomly.
4. many spots distributed evenly.

Interference: Young 1801

Requirements of two source and single source double-slit systems for the production of fringes.

The appearance of the interference fringes produced by a double slit system,

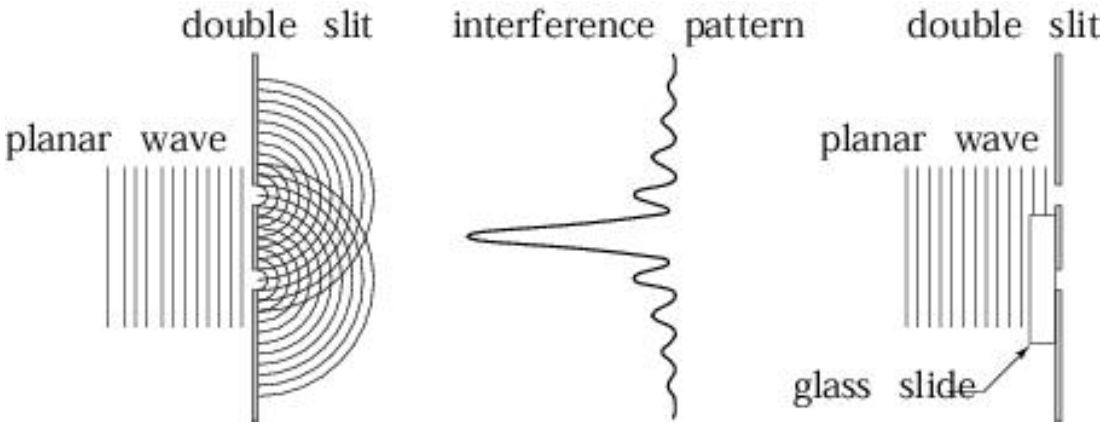
$$\text{fringe spacing } w = \frac{\lambda D}{s},$$

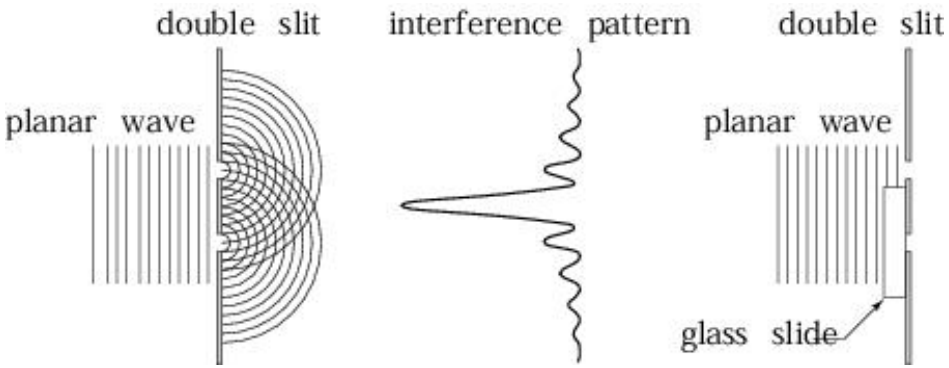
where s is the separation of the slits.

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Concept question

An interference pattern is formed on a screen by shining a planar wave on a double-slit arrangement (left). If we cover one slit with a glass plate (right), the phases of the two emerging waves will be different because the wavelength is shorter in glass than in air. If the phase difference is 180°, how is the interference pattern, shown left, altered?





1. The pattern vanishes.
2. The bright spots lie closer together.
3. The bright spots are farther apart.
4. There are no changes.
5. Bright and dark spots are interchanged.

Concept question

Suppose we cover each slit in Young's experiment with a polarizer such that the polarization transmitted by each slit is orthogonal (at 90°) to that transmitted through the other. On a screen behind the slits, we see:

1. the usual fringe pattern.
2. the usual fringes shifted over such that the maxima occur where the minima used to be.
3. nothing at all.
4. a fairly uniformly illuminated elongated spot.

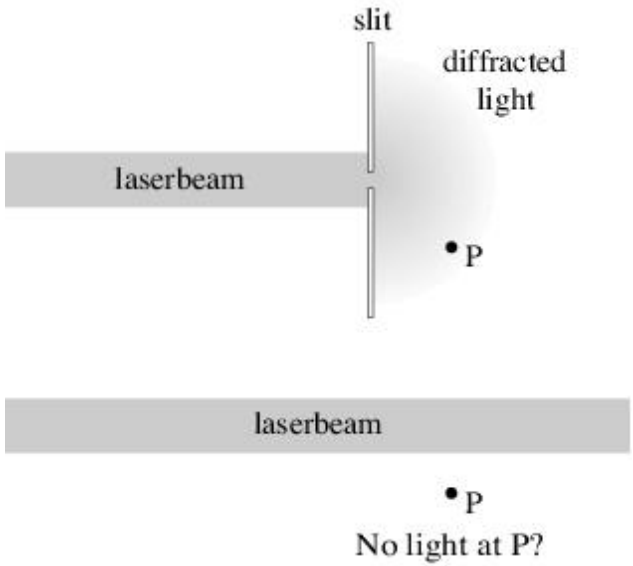
Concept question

Diffraction occurs when light passes a:

1. pinhole,
2. narrow slit,
3. wide slit,
4. sharp edge,
5. all of the above.

Concept question

Okay, then why doesn't a laser beam without any slit spread out in all directions?



1. Because all waves that spread interfere destructively.
2. It does spread, but the spread is so small that we normally don't notice it.
3. We can't apply diffraction physics anywhere but in slits and apertures.

Diffraction

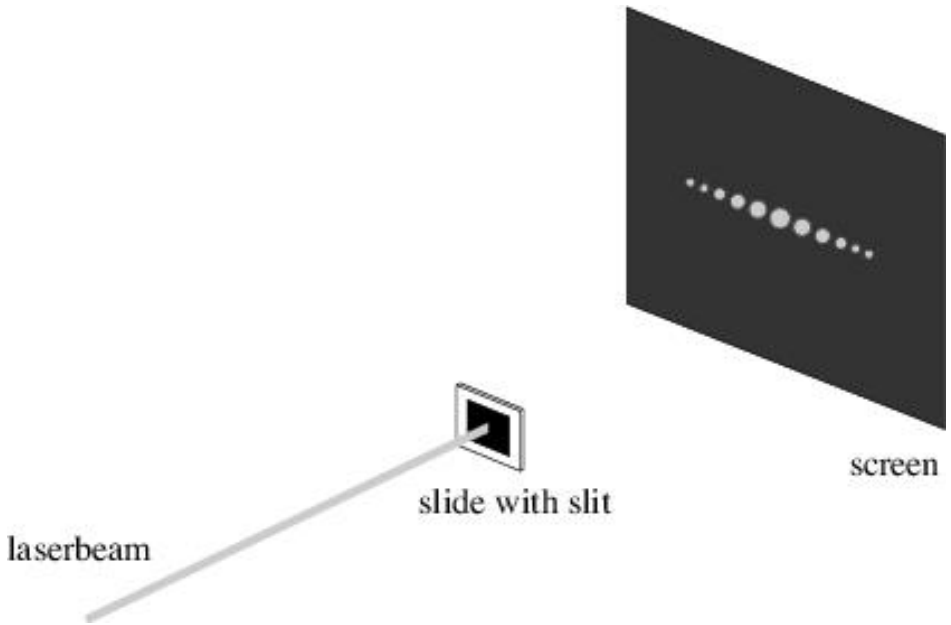
Diffraction is rather easy to observe, e.g. the shadow of your hand in direct sunlight, a pencil illuminated by a 'point source' (you need a strong source; a high-intensity lamp shinging through a small hole works well), 'floaters' in your eyeballs, driving at night with rain on your glasses (interesting, as diffraction by transparent objects isn't normally considered) or the fringes you can see between your thumbs.

At A-level we meet only the special case of Fraunhofer diffraction (this is where the light source and the screen are far away from the aperture or obstacle causing diffraction). This is because (a) it is practically important as it is applicable to systems of lenses which form an image of an extended source or object, and (b) because it is simpler than the more general case of Fresnel diffraction (which you will meet at university).

Concept Question

The pattern on the screen is due to a narrow slit that is

1. horizontal.
2. vertical.



Single slit $\longrightarrow$ double slits $\longrightarrow$ n slits

The appearance of the diffraction pattern from a single slit.

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Diffraction grating

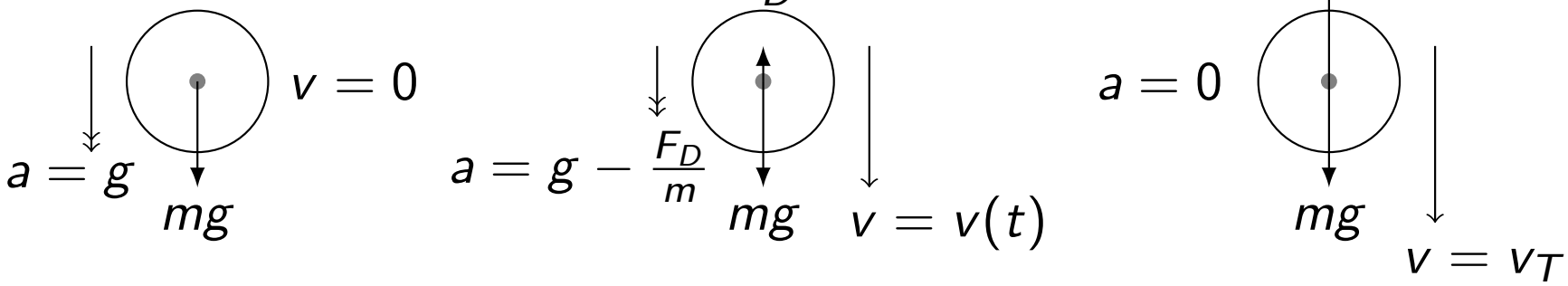
Derivation of $d \sin\theta = n\lambda$, *where* n *is the order number.*

Applications; e.g. to spectral analysis.

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Derivation of $d \sin\theta = n\lambda$

For constructive interference at the nth order maximum, the path length to the observer must be a whole number of wavelengths different between adjacent slits of the diffraction grating.



Start | After short time | Some time later

Concept Question

A diffraction grating is illuminated with yellow light at normal incidence. The pattern seen on a screen behind the grating consists of three yellow spots, one at zero degrees (straight through) and one each at $\pm 45^\circ$. You now add red light of equal intensity, coming in the same direction as the yellow light. The new pattern consists of

1. red spots at 0° and $\pm 45^\circ$.
2. yellow spots at 0° and $\pm 45^\circ$.
3. orange spots at 0° and $\pm 45^\circ$.
4. an orange spot at 0°, yellow spots at $\pm 45^\circ$, and red spots slightly farther out.
5. an orange spot at 0°, yellow spots at $\pm 45^\circ$, and red spots slightly closer in.

Concept Question

By passing red laser light through a diffraction grating, you produce an interference pattern on a screen. Changing to green laser light with the same diffraction grating, you would produce a new pattern that is

1. the same as the red.
2. the same as the red, except that the pattern is sharper.
3. similar to the red, but the pattern is more spread out.
4. similar to the red, but the pattern is more compressed.