# Young's slits revisited

## Surface waves shed new light on classic experiment

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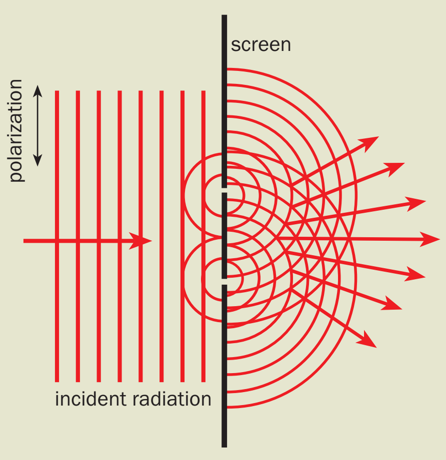
Few experiments in physics are better known than Thomas Young's double-slit experiment. For more than two centuries this simple set-up – in which a beam of light produces an interference pattern when it passes through two closely spaced slits – has been used to demonstrate the wave nature of light. You might therefore think that there is nothing new to discover using this experiment, but that is not the case.

Hugo Schouten of the Free University in Amsterdam and co-workers have now revisited Young's famous experiment using slits in a metal screen, and found extra effects due to the excitation of surface waves running along the screen (*Phys. Rev. Lett.* **94** 053901). This causes the overall intensity of the interference pattern to vary periodically with the wavelength of the incident light. Perhaps even more surprisingly, the cause of the novel effects lies at the entrance of the slits, rather than at the exit.

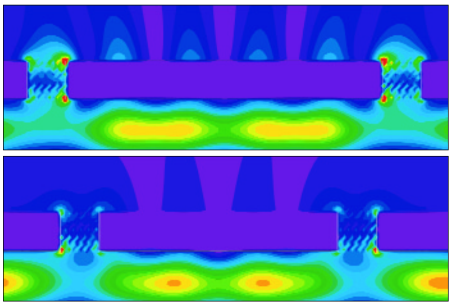
### Change in intensity

Before discussing this new development, it is worth reflecting upon Young's original experiment. Today, it may seem obvious that light behaves as a wave, but in the late 18th century Newton's "corpuscular" theory of light held sway. Young's results, which could only be interpreted if light was a wave, were therefore not readily accepted. Curiously enough, Young's original paper published in *Philosophical Transactions* in 1804 does not actually detail the famous double-slit experiment that we are taught in school. What is recorded is how the 21-year-old physicist inserted a thin piece of card in the path of a light beam emanating from a thin slit, and how he then observed fringes caused by the interference of light diffracting around both sides of the card.

In the latest incarnation of Young's experiment, Schouten and co-workers at Leiden University, Delft University of Technology, both in the Netherlands, and the University of North Carolina in the US use a thin metal screen containing two narrow slits. The slits themselves are narrower than the wavelength of light used to illuminate them (740–830 nm) and are separated by a distance corresponding to several optical wavelengths. The front of the screen is coated with a layer of gold, which is highly reflective at these wavelengths, while the back surface is made from titanium, which is not such a good mirror. As expected, the Dutch–US team clearly observed bright and dark fringes, corresponding to regions where the two emerging beams interfered constructively and destructively.



Classic diffraction – Young's double-slit experiment, in which a plane wave (vertical lines on the left) is diffracted through two narrow slits to produce an interference pattern of light (arrows on right) and dark fringes, proves that light behaves as a wave. In the new experiment, the slits were cut from a metal screen coated with gold on one side and titanium on the other. When the incident light was polarized at right angles to the screen, it caused surface plasmon waves (not shown) to propagate between the slits, which modulated the total intensity of the interference pattern.



These simulations illustrate how the intensity of surface waves varies in the vicinity of the slits when electromagnetic radiation is incident from below (red/orange represents high intensity). Bright fields exist when the distance between the slits is 5λ/2, where λ is the wavelength of the surface plasmon (top). Also visible are four peaks (grouped as two pairs) in the amplitude just before the metal plate. By contrast, no field enhancement at the slits takes place when they are separated by 4λ/2 (i.e. an even number of half-wavelengths) (bottom).

However, when the researchers varied the wavelength of the incident light, they found that the intensity of the interference pattern oscillated with the wavelength in a manner dictated by the spacing between the slits. Furthermore, the team found that this result only holds for light that is polarized perpendicular to the slits.

The reason for this is that metals can support electromagnetic waves called surface plasmons. These waves arise naturally when radiation that has an electric-field component perpendicular to the metal surface couples with the charge density of the free electrons in the metal. For a flat metal surface, a surface plasmon excited at a particular frequency has more momentum (and therefore a shorter wavelength) than a grazing light wave of the same frequency. As a result, these "resonant surface modes" are not normally excited unless additional momentum is available to enhance the momentum of the incident photon.

In the new experiment this extra momentum is provided by the slits themselves; they diffract as well as reflect and transmit electromagnetic radiation, thereby imparting momentum to the photons in the perpendicular direction. Thus we expect the radiation to excite surface waves on both sides of the metal film, provided it is polarized at right angles to the slits. The electromagnetic properties of gold (namely its permittivity) at these wavelengths means that the surface-wave propagation distance is about 80 μm on the gold side of the slits. This is much bigger than even the largest slit separation used, which means that a surface standing wave can be established on the surface. This changes the intensity of radiation at the slits and therefore affects the intensity recorded in the interference pattern.

### Surface waves

If the metal was a perfect conductor, the wavelength of the surface wave supported by it would be the same as that of the incident light. We would therefore expect to see periodic effects in the overall transmitted intensity when the distance between the edges of the slits is an odd multiple of half the wavelength of the radiation. In reality, the momentum of the surface wave is only a few per cent larger than that of a photon of the same frequency, so the standing surface plasmon wave is very close in wavelength to that of the free photon.

Schouten and colleagues have avoided setting up standing surface waves on both metal surfaces by using titanium on the exit surface, which has a surface-plasmon propagation distance of about 5 μm – i.e. less than the spacing of the slits. This avoids the complication of having two sets of surface waves, which could interact with one another at the slits and confuse the interpretation of the experiment.

It may appear that to avoid the effects of surface waves in Young's slit experiment we require a perfect absorber. However, we now know that this is not the case: all we need to do is to rotate the plane of polarization so that it is parallel to the slits. In this arrangement no surface plasmon waves can be excited and, as Schouten and co-workers report, no wavelength-dependent intensity modulation will occur.