This result has a number of implications. First, it is a useful reminder to everybody who studies the physics of materials that tiny quantities of impurities can transform the physics. In chemistry 99% purity is often regarded as good, but here we have a material that is 99.99% pure – yet only 0.008% of the sample is determining its behaviour. It is little wonder that decades of work have been devoted to perfecting the growth and purity of samples of inorganic semiconductors.

Fortunately (and unusually) the trace amount of impurity is beneficial in the latest polymer experiments, which means that small amounts of palladium or other heavy metals could be used to produce light emission from triplets, and hence to improve the efficiency of polymer LEDs. A probable limitation is that only modest brightness will be possible with these low concentrations of metals.

Another consequence will be that doping at this very low level will provide a convenient way of "seeing" triplets and hence studying their physics. For example, light emission from both singlets and triplets can be observed in the Mainz experiment, and the energy difference of 0.6 eV indicates that the excited states are strongly bound and localized, in contrast to inorganic semiconductors. Moreover, we will need to assess the extent to which previous photophysical studies of materials might have been influenced by such impurities.

Finally, everyone involved in making light-emitting polymers will have to remember that 99.99% pure is not good enough, and that at least 99.999% purity is needed. But will even that be good enough?

Pipe organs: physics in an action

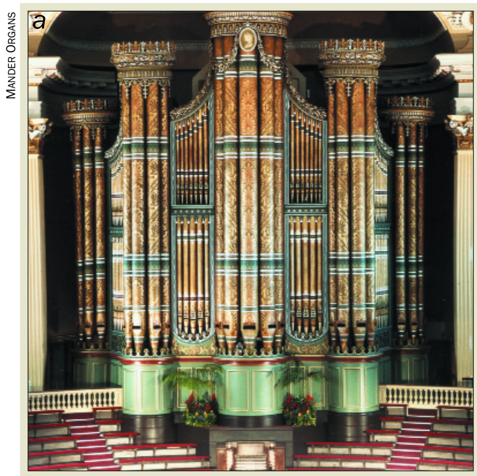
Lots of basic phenomena come into play in the action of a pipe organ, as **Colin Pykett** explains

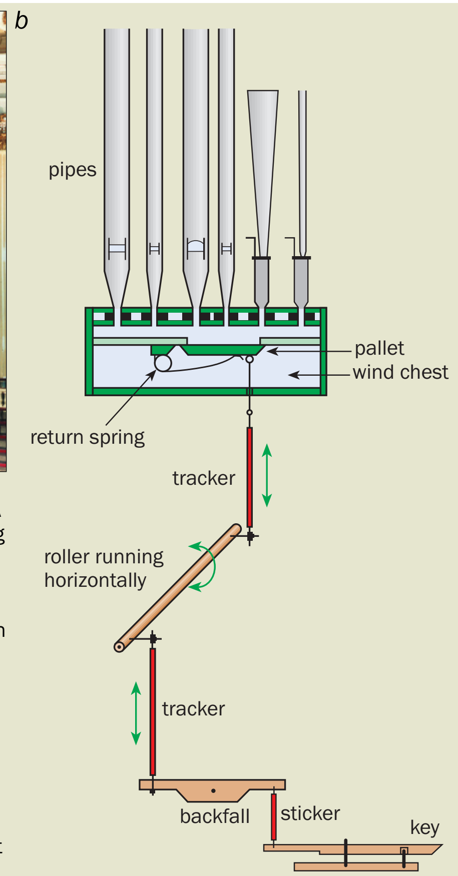
The pipe organ is the most impressive of all musical instruments, often reaching heights of metres or even tens of metres in concert halls and churches. One of the most crucial parts of the organ is the "action" – the mechanism that links the keys and the pipes. If the action is badly designed, then the instrument can be difficult to play or may even be unplayable.

The figure shows the elements of a typical action, in which the distance between the keys and the pipes is bridged in two ways: "trackers" that transfer the key movement vertically and "rollers" that translate it horizontally. In the largest organs the trackers may be tens of metres long. Problems with the playability of organs can arise from the weight of touch needed to play a note. This is governed by the air pressure in the "wind chest" and the area of the valve or "pallet" that admits air to the pipes.

The air pressures involved are quite low, but when they are multiplied by the area of the valve then the total force that the player's finger has to overcome can be uncomfortably large. In 1846, for example, the composer Mendelssohn complained that he "would not have the strength to play a fugue" on the organ in Birmingham's Town Hall "without a very long practice".

There is a second, more subtle, problem that occurs when the player releases the key. Ideally the pallet should close quickly under the influence of a spring to end the note. However, the spring is often not strong enough to overcome the inertia of the action, which prevents the pallet from closing quickly enough. If the release time is too long (over about 60 milliseconds), it limits the speed at which the organ can be played, which is clearly unacceptable for many pieces of music.





(*a*) Modern organs, such as the one in Birmingham Town Hall (above), can be several metres in height. A knowledge of basic physics and modern engineering is needed to ensure that such large instruments are not difficult to play. Indeed, Mendelssohn once complained that he did not have the strength to play the previous organ in Birmingham. (*b*) A typical organ mechanism (not to scale) with the traditional names for the different components. To play a note the organist depresses a key, which opens the "pallet" and allows air to reach the pipes of the organ. There is an additional mechanism, not shown, in which "sliders" – long strips of wood that contain holes – also control the flow of air to the various "ranks" of pipes. These sliders run perpendicular to the plane of the diagram and are controlled by the "stops" that are pulled in and out by the organist.

Helping hands

Mendelssohn's problem was solved using typical Victorian ingenuity. As early as 1826 the inventor of the electromagnet William Sturgeon had tried to open pallets with his invention. Although initial attempts failed, reliable electric actions became available before the end of the century. These prevailed until about the 1950s, when players began to lament the lack of a direct connection with the pipes. How would a violinist react, they asked, if he or she was told that their instrument could only be played by means of electricity?

Consequently there was a return to the centuries-old "tracker action", but the old challenges remained: the pallet must be large enough to get enough air to the pipes, but not so large that the playing weight is excessive. This requires a combination of aerodynamics and basic physics. Moreover, the total mass of the action must be kept to a minimum so that the pallet can close rapidly when the key is released. Those moment-of-inertia calculations that seemed so dry at school suddenly spring to life in an organ.

These design issues are fundamentally simple, and there is now a body of opinion that accepts that they limit the size of organ that can realistically be built using a mechanical action. When a pallet has to supply air to many pipes, its size may mean that it is impossible to achieve a light enough key touch without pneumatic or electric assistance of some kind. But as soon as we resort to such measures, we are compromising the musical design ideals of a purely mechanical system. So what does an organ builder do when faced with designing a large instrument for a concert hall?

A pragmatic answer is emerging from among the ranks of the world's foremost performers. Some of today's large instruments, such as those in Manchester's Bridgewater Hall and at Christchurch Priory, boast dual consoles: one console has a mechanical action, while the other uses an electrical action. The mechanical action is buried inside the organ case and cannot be moved, while the console with the electrical action is connected to the pipes by copper or fibre-optic cable and can be moved. There is strong evidence that many organists prefer the electric console to the mechanical one, and we might have to accept that an electric action is the only practical option for playing the largest instruments.

Electric actions

So why can we make electric actions nowadays when William Sturgeon could not? One answer is simple – we can push as much current as necessary through the electromagnet to make it sufficiently powerful for the job. Sturgeon was limited by the currents available from primary batteries. However, the old problem of the release time is still important.

The use of relatively powerful electromagnets – capable of supporting about 0.5 kg – implies the use of substantial armatures, and these have an inertia that increases the release time of the system. Moreover, the decay of the current in the magnet coil has to be controlled to prevent large back voltages being generated when the key is released. The need to control the decay of the current accounts for about 20% of the total release time.

Recent approaches include proportional electric servos in which the magnet that opens and closes the pallet faithfully follows the movement of the key, rather than simply jerking the pallet fully open when the key is pressed. Such an action has the musical advantages of a mechanical action yet none of its limitations regarding instrument size.

A number of organs with modern servo actions (and other pretty sophisticated electronics) have been built, to acclaim of many musicians. However, the field is still wide open for anyone who wants to combine basic Newtonian physics with modern engineering to help make what is one of the world's most venerable musical instruments more versatile.

Colin E Pykett was a physicist in the Ministry of Defence and now does freelance research in musical-instrument technology

● www.pykett.org.uk

Highlights from PhysicsWeb

Evidence for dark energy grows

Radio astronomers have found new evidence that most of the energy in the universe is in the form of "dark energy". By comparing the distribution of gravitational lenses that had been found by the Cosmic Lens All Sky Survey with data on the distribution of galaxies, an international team has shown that most of the energy in the universe is in the form of dark energy – a mysterious form of energy that repels matter.

Nanowires within nanowires

As nanowires become more widely used in the semiconductor industry, researchers are trying to fabricate more complicated nanostructures for device applications. Now scientists at Harvard University have made "core-shell" nanowires that contain a germanium core surrounded by a silicon shell, and "triple decker" wires made of silicon, silicon oxide and germanium. The new structures allow a semiconducting wire to be encased in an insulating shell. The team is also working with Intel to integrate nanowire transistors with conventional semiconductor devices.

Star sheds light on element creation

Stars in the early universe should have contained only tiny quantities of elements heavier than helium – or "metals" as they are known in astronomy. Researchers have now found a star that contains only 1/200 000th of the amount of metal that is found in the Sun – a factor of 20 less than the previous record for a low-metal star. Such stars could provide important information about star formation and the age of the universe.

Lasers target hard drugs

The late Art Schawlow, who received the Nobel prize for his work on laser spectroscopy, once said that "anything will lase if you hit it hard enough". Schawlow's belief that all materials have useful optical properties has now been taken to a new extreme by physicists in India, who have applied the technique of laser spectroscopy to investigate two of the most addictive substances known – heroin and morphine. The team claims that its approach could be used to detect trace amounts of the drugs.

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