Making sense of scent

A new angle on our sense of smell, probably the most overlooked of the senses, shows how subtle quantum phenomena can be.

Marshall Stoneham | *University College London, UK* | a.stoneham@ucl.ac.uk

The salesperson in a car showroom will offer you a choice of colors, both for the car body and its upholstery. They're unlikely to suggest you choose how the car smells, even if classy, rich leather scent could be a selling point. My first car was older than me, with an ageing cheese in the boot but, being a graduate student, I bought it anyway.

Some scents appeal to most people, like cut grass or freshly baked bread. Many will be acutely conscious of scents for personal use, like soaps or shampoos. Yet we are less sure of the character of a scent than of a color or a sound. The color blind are more likely to know that they are missing something than those who have a limited sense of smell.

Our senses use special structures that respond to external stimuli like light, sound, or volatile molecules. Such structures are exquisitely sensitive, and the signals they send to the brain yield our experiences of colors, frequencies, and odors. The brain works fast, even with incomplete information, so we can respond to danger or opportunity, or coordinate experiences. But there is value in understanding how these signals start. How does a photon create a signal that the brain can interpret? Does the eye resemble a photocell? Our views of how photocells work tempt us to believe that the eye is much the same, just more complex. But how does the nose create a signal when a scent molecule comes along? Is the nose like a gas sensor?

Let's think about the similarities and differences between gas sensors, electronic noses, human noses, and their analogues in the animal kingdom. Gas sensors detect specific small molecules, typically CO, ozone, SO_2, NO, and so on; molecules with no distinctive smell. Not surprisingly, the nose doesn't pay much attention to molecules like H_2O, O_2, or N_2, since these are always around. But, whereas the human nose ignores CO_2, the fruit fly is acutely sensitive to minute changes in CO_2 concentration. Electronic noses, like gas sensors, are designed to respond only to particular molecular species. The human nose can find that some very different molecules smell similar, like H_2S and borane. A human nose, offended by a sulfurous stink, would not be happy if this were checked by an electronic nose sensitive only to H_2S. So what is going on?

Gas sensors look simple. The gas often causes some complex oxide to change its electrical properties. Natural explanations might be either straightforward electron transfer, or a chemical reaction of the gas with the outer surface of the oxide. It is usually easy to invent conceivable reaction chemistries for any particular complex oxide. But when one checks a large ensemble of data for many oxides and many gases, a different picture seems more likely: the gas molecule often reacts not with the surface, but with some adsorbed species found on many oxide surfaces; the oxygen molecular ion O_2^- is often suggested. This different mechanism changes sensor behavior in substantial and systematic ways.

Within our bodies, there are many sites that give a specific response to a particular molecule. Proteins and large drug molecules achieve a remarkable specificity. They seem to do this partly by a 'lock and key' mechanism[1]: the molecule must have exactly the right shape to dock with its target. Presumably, what happens next is decided by which regions of the large molecule are sticky, charged, hydrophilic, or hydrophobic, so the docked molecule applies forces to its target to actuate subsequent steps.

This 'lock and key' analogy is addictive, but seems inadequate for small neurotransmitters like serotonin or NO, and is clearly incomplete for the small, volatile scent molecules. Ferrocene and nickelocene have almost exactly the same shape, with deviations much smaller than thermal fluctuations, yet they smell utterly different. Such anomalies led to the idea that molecular vibrations were the clue: if the nose could offer a vibrational spectrometer, many of these anomalies vanish[2]. Borane and H_2S should indeed smell the same; ferrocene and nickelocene should smell different. But how can the nose achieve this? Luca Turin[3] imaginatively suggested inelastic electron tunneling: an electron could tunnel across a receptor only by losing the right amount of energy to a vibration of the molecule, and this electron would actuate the receptor. His picture raises obvious questions. Shouldn't there be an isotope effect? Some workers find one, others do not. Why don't all enantiomers (molecules with left- and right-handed forms) smell the same? The brain uses many receptors to define a smell, and the fit of left- and right-handed forms into receptors (which are chiral themselves) will differ, affecting intensities of the signals the brain receives. Are tunneling rates really big enough, relative to tunneling when there is no scent molecule? Does the mechanism seem physically possible, given what we know about the electronic properties of biomolecules?

What emerges from detailed calculations is that the model seems both physically credible and robust[4]. Your nose works more like a swipe card than a lock and key. You have a quantum sensor in your nose.

REFERENCES

1. Fischer, E., *Ber. Dtsch. Chem. Ges.* (1890) **23**, 2611
2. Dyson, G. M., *Chem. Ind.* (1938) **57**, 647
3. Turin, L., *Chem. Senses* (1996) **21**, 773
4. Brookes, J. C., Hartoutsiou, F., Horsfield, A. P., and Stoneham, A. M., *Phys. Rev. Lett.* (2007) **98**, 038101