the most important energy-transfer step in metabolism (the maximum rate of oxidative ATP synthesis per unit of mitochondrial membrane) doesn't vary with body mass[11]? What about the safety factors that seem to be built into many functions — how do they affect this kind of overall relationship? In fact, allometric relations may mask various features, such as the fact that the metabolic scope of certain athletic species of larger animals may be two to five times greater than is typical for that size of animal[9]. Thus, at MMR, the most athletic mammal, the pronghorn antelope of the Rocky Mountains, consumes oxygen at the same rate as a mouse[12] — so body size is not a universal primary determinant of energetics.

Whether Darveau *et al.*'s model[3] is the ultimate wisdom remains to be seen, but it does give the field of comparative integrative physiology a new thrust. And it does away, perhaps regrettably, with a myth — that in comparative biology a single magic number might unlock all of nature's secrets. ■

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1. Rubner, M. *Z. Biol.* **19,** 535–562 (1883).
2. Kleiber, M. *Hilgardia* **6,** 315–353 (1932).
3. Darveau, C. A., Suarez, R. K., Andrews, R. D. & Hochachka, P. W. *Nature* **417,** 166–170 (2002).
4. Schmidt-Nielsen, K. *Scaling: Why is Animal Size So Important?* (Cambridge Univ. Press, 1984).
5. Dodds, P. S., Rothman, D. H. & Weitz, J. S. *J. Theor. Biol.* **209,** 9–27 (2001).
6. West, G. B., Brown, J. H. & Enquist, B. J. *Science* **284,** 1677–1679 (1999).
7. Taylor, C. R. *et al. Respir. Physiol.* **44,** 25–37 (1981).
8. Srere, P. A. *Biol. Chem. Hoppe-Seyler* **374,** 833–842 (1993).
9. Weibel, E. R. *Symmorphosis* (Harvard Univ. Press, Boston, 2000).
10. Weibel, E. R. *et al. J. Exp. Biol.* **199,** 1699–1709 (1996).
11. Hoppeler, H. & Lindstedt, S. L. *J. Exp. Biol.* **115,** 355–364 (1985).
12. Lindstedt, S. L. *et al. Nature* **353,** 748–750 (1991).

Applied physics

Bridge for the terahertz gap

Carlo Sirtori

A device has been invented that produces radiation in the terahertz range. It is a considerable feat of semiconductor fabrication, and could be used in a wide range of applications.

In modern communications, information is transmitted by modulating either the amplitude or the frequency of electromagnetic waves. But not all of the electromagnetic spectral range can be exploited for this purpose, a deficiency that is addressed by Köhler *et al.* on page 156 of this issue[1].

The electromagnetic range that is used is vast, crossing the hertz span from kilo (10^3), through giga (10^9) to tera (10^{12}), and so running from radio to optical frequencies — that is, from about 10 kHz (wavelength around 30 km) to about 300 THz (wavelength around 1 μm). Depending on whether we are listening to the BBC, or making a telephone call on a mobile phone or across the ocean, we are connected through signals that are carried by radiation at 100 kHz (radiowave), 3 GHz (microwave) or 300 THz (near-infrared light). Semiconductor devices are the enabling components for all of these technologies. Oscillating circuits based on high-speed transistors efficiently produce radiation in the low-frequency region; at high frequencies, semiconductor lasers generate coherent light for telecommunication links based on optical fibres.

As shown in Fig. 1, however, the frequency ranges of the two technologies do not meet. On the one hand, transistors and other quantum devices based on electron transport (see, for instance, ref. 2) are limited to about 300 GHz (50 GHz being the rough practical limit; devices much above that are extremely inefficient). On the other hand, the wavelength of semiconductor lasers can be extended down to only 10 μm (about 30 THz)[3]. Between the two technologies lies the so-called terahertz gap, where no semiconductor technology can efficiently convert electrical power into electromagnetic radiation. Köhler *et al.*[1] describe a new semiconductor laser that produces intense radiation at 4.4 THz (wavelength 67 μm), by injecting electrons into a quantum structure. There is still a long way to go before commercial devices based on this principle can be mass-produced. But this demonstration shows that they might be feasible: it could result in the bridging of the terahertz gap between transistor and laser technologies.

Like other semiconductor lasers, Köhler and colleagues' device is composed of an active region, where photons are produced, and an optical waveguide that confines the radiation. But these two fundamental constituents of a laser must meet completely different demands in the terahertz region. The main difficulties to be overcome are the high intrinsic optical losses induced by the free electrons in the material; the large size of the optical mode — imposed by the wavelength; and the short lifetime of the excited state of the laser transition, in which electrons accumulate to create the 'population inversion' necessary for lasing. Köhler *et al.* have carefully addressed each of these points.

The waveguide is an innovative hybrid

100 YEARS AGO

One of the most remarkable architectural structures in existence is the left-handed spiral staircase in the Chateau de Blois, Touraine, built during the sixteenth century from designs by Leonardo da Vinci. In a well-illustrated and thoughtful article … Mr. Theodore Cook shows that the design of this staircase corresponds so exactly with the spirals on the common Mediterranean shell known as *Voluta vespertilio* as to leave little doubt that the artist had that shell before him as his model. The spiral on the central column of the core of the staircase corresponds exactly, for instance, with the spiral ridges on the columella of the volute, as seen in section. This of itself would be strong, although perhaps not absolutely convincing, evidence as to the origin of the design. But the staircase has also an exquisite outer balustrade, which shows a correspondence to the coils on the external spire of the shell as close as that which obtains between the interior of the staircase and the columella of the volute … It is remarkable, however, that the spirals in the staircase run in the reverse direction to those in normal examples of the shell, that of the central shaft being left-handed instead of right-handed.
From *Nature* 8 May 1902.

50 YEARS AGO

Dr. Derek Price has recently written two articles … in which he describes some very interesting facts brought to light by a recent examination of a manuscript entitled "The Equatorie of the Planetis" in the Perne Library, Peterhouse, Cambridge. This was written in 1392, and if, as is now thought probable, it is a hitherto unknown work of Chaucer, the manuscript is of great importance as it would provide for the first time an example of Chaucer's handwriting and also an uncorrupted specimen of his language and spelling. Various lines of evidence suggest that Chaucer was the author and not Simon Bredon, to whom it was once attributed, as it is now known that the latter died on or before 1372, the date when his will proved. Probably the strongest evidence for the authorship is found in a note adjacent to a table for the conversion of years to solar days … The "Equatorie" appears to be a free adaptation from an Arabic or Persian source, presumably through a Latin translation.
From *Nature* 10 May 1952.

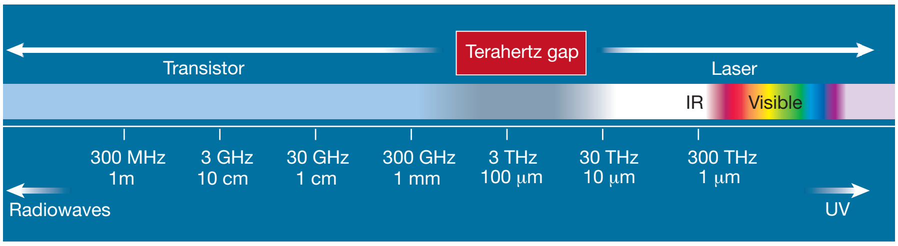

Figure 1 **The terahertz gap. The gap, lying roughly between 300 GHz (0.3 THz) and 30 THz, exists because the frequencies generated by transistors and lasers, typical semiconductor devices, don't overlap. No current semiconductor technology can efficiently convert electrical power into electromagnetism in that range. But the 'heterostructure laser' produced by Köhler *et al.*[1] might, in due course, meet the demand for radiation sources at these terahertz wavelengths.**

between a 'metallic microwave stripe-line' and a 'surface plasmon waveguide', a concept already used for semiconductor lasers that produce radiation in the mid-infrared range[4]. The propagation losses measured by Köhler *et al.* are of the order of 10 cm^{-1} — that is, a reduction of about a factor of three for each millimetre travelled. This is much the same as in the mid-infrared, where the wavelength is ten times smaller, and is surprisingly low: free-carrier absorption increases with the square of wavelength, so one would expect much higher optical losses at around 70 μm. The trick is that the only absorbing region is a narrow layer of heavily doped semiconductor that keeps half of the radiation mode in the active region, and leaves the other half in a loss-less substrate[5]. The waveguide design principle and radiation 'mode' profile are shown in Fig. 2 of the paper on page 157.

The active region is made of many identical quantum structures connected in series. In this quantum cascade scheme[6], electrons are selectively injected in an excited state; they then 'jump' to a lower energy state, emitting light; and finally they are recycled in the next structure in the series. To obtain laser action, most of the electrons have to be in the excited state. When, as in this case, the energy transition between the excited and lower energy states is a few meV, the electrons tend to scatter and the excited state has too short a lifetime for effective population inversion. Scattering is a function of the electron density, and Köhler *et al.* have tackled the problem by spreading the total population inversion over a sequence of 104 repeat periods in the quantum structures. In this way, the total of the electron population contributing to the optical gain is comparable to that of a conventional diode laser, but is two orders of magnitude less per period. It means, however, that the quantum structure constituting the active region is more than 10 μm thick and contains almost 1,500 semiconductor layers, each of which is only a few nanometres thick and needs precise doping. Creating such a thick and complicated structure was a considerable feat of semiconductor-crystal growth.

This is not the first semiconductor laser that can operate in the terahertz region. More than 15 years ago, lightly doped germanium showed laser action at low (cryogenic) temperatures and under crossed electric and magnetic fields[7]. At the moment, the performance of the two types of device is comparable, but Köhler *et al.*'s heterostructure laser represents major progress because of the scope for refinement. The main difference between the two structures is in the way they are conceived. The germanium laser depends on the fundamental properties of the bulk material, which are inflexible and difficult to manipulate. The laser designed by Köhler *et al.*, by contrast, is the result of sophisticated quantum engineering, with the design of the structure determining the optical (emission frequency) and electrical properties. It is the control of device properties, and the flexibility offered by semiconductor crystal growth, which mean that improvements leading to a commercial terahertz technology may well be possible.

What applications might take advantage of such a technology? Terahertz emitters would be in great demand for use in astronomy and studies of Earth's atmosphere — even if this is only a niche market, it is a well-defined and long-lasting one. But medical imaging, wireless telecommunications, chemical analyses using molecular spectroscopy and intra-building links (terahertz radiation can pass through construction materials) are also areas that could benefit greatly. The most enticing and profitable application is of course in telecommmunications, in greatly extending the frequency band available. Nevertheless, two main points need to kept in mind. First, the atmosphere becomes very opaque above 1 THz, absorbing radiation at these frequencies. Second, no efficient or fast terahertz detectors are yet available. The challenge is, therefore, to move to even lower frequencies — although meeting this challenge would mean moving into a competitive arena with existing transistor technology.

Finally, there is just a little déjà vu about the paper by Köhler *et al.*[1]. It seems that the latest trends in semiconductor laser are taking us back to the origins of laser technology — back to the late 1950s, and to the microwave frequencies exploited in the invention of the maser. ■

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1. Köhler, R. *et al. Nature* **417**, 156–159 (2002).
2. Rodwell, M. J. W. *et al. IEEE Trans. Electron Devices* **48**, 2606–2624 (2001).
3. Beck, M. *et al. Science* **295**, 301–305 (2002).
4. Sirtori, C. *et al. Optics Lett.* **23**, 1366–1368 (1998).
5. Ulirch, J. *et al. Physica B* **272**, 216–218 (1999).
6. Faist, J. *et al. Science* **264**, 553–556 (1994).
7. Andronov, A. A. *et al. Pis'ma Zh. Eksp. Teor. Fiz.* **40**, 69 (1984). Transl. *JETP Lett.* **40**, 804 (1984).

Palaeoecology

Climate records spruced up

Peter D. Moore

Pollen analysis is a valuable tool in helping to reconstruct past climatic conditions. Such studies can be informative on local as well as regional scales, as findings with fossil spruce pollen in Maine show.

Taking the past as a guide to the future is an approach used in many endeavours. One is the modelling of future climate change, and in such work, assemblages of fossil pollen are among the sources of evidence about the past. Such assemblages accumulate in the stratified sediments of lakes and peat deposits, and they are of course derived from, and reflect, the vegetation of former times.

But pollen travels far and wide, so most studies can provide only broad indications of past vegetation and lack the resolution needed to reconstruct local features of palaeoclimate. By using a series of small, forest-enclosed hollows in New England as their source of pollen stratigraphy, however, Schauffler and Jacobson[1] have succeeded in obtaining the required spatial resolution for that region. As they report in *Journal of Ecology*, they are able to conclude that the coastal region of Maine became distinctly cooler than inland areas around 5,000 years ago, and so show the usefulness of such studies.

The value of pollen analysis as a source of information about past climatic conditions has been recognized for about a century. For most of that time, the sites most prized for such studies have been large lakes and