about 0.2% of the electron's kinetic energy can be extracted in each pass through the magnets but it is planned to increase the efficiency by circulating the electrons in a storage ring, which should also raise the mean power available.

Conventional electron storage rings have a large amount of power pumped into them which is dissipated in the incoherent synchrotron radiation. Ultimately this new laser, fixed to a storage ring, could conceivably channel a substantial fraction of the power into stimulated radiation making it available as a well collimated beam of fixed wavelength.

In a conventional laser transitions are stimulated between electronic states of atoms. The power is limited by the pumping process for energising the atoms, and the frequency by availability of suitable electronic transitions. Only recently have continuously tunable lasers become available and the range of tuning is limited to typically less than 1% of the operating wavelength. In the new process massive amounts of energy are available in the kinetic energy of the electron beam and the wavelength of radiation can be simply varied by a large factor. It is expected that lasing action can be observed at wavelengths varying from a few 100 μm down to 0.1 μm.

The laser operates by passing the electron beam through a helical magnetic field. If the spontaneous radiation is confined in a cavity, it can stimulate further radiation, the gain peaking at a wavelength

$$\lambda_s = \frac{\lambda_q}{2\gamma^2}\left[1 + \frac{1}{(2\pi)^2}\frac{\lambda_q{}^2 r_0 B^2}{mc^2}\right]$$

where λ_q is the period of the helix, B the magnetic field strength, c the velocity of light, r_0 and m the classical electron radius and mass of the electron respectively; the electron energy is γmc^2. The electron chases closely after the emitted radiation with almost the velocity of light so that pulses from successive periods of the helix fall very close together and the wavelength of radiation is much shorter than the helix period. A 3.2-cm period helix and 43.5 MeV electron beam generate 3.4 μm radiation. (The helix used in the experiment was 5.2 m long.) It is this relativistic shift of the wavelength which gives the laser its great tunability. The energy of the electron beam being proportional to γ, the operating wavelength, λ_s, scales inversely as the square of the energy.

The immediate difficulty is that the laser requires high currents to produce usable gain, posing problems of stability in storage rings operating at what are rather low electron energies. The theory of storage rings is well understood and these difficulties can probably be overcome to a satisfactory extent. Less well understood is the perturbation that the huge radiation fields building up in the cavity will have on the electron orbits. Even in these preliminary experiments $\frac{1}{2}$ MW of peak power was present in the cavity and this amount of radiation could possibly upset the operation of a storage ring.

Devices producing large amounts of power over a wide spectral range are bound to find wide application. It is conceivable that one of the first uses might be as a tunable source of infrared radiation. Current sources tunable in the 20–200 μm range are of very low power, 10 mW or less, whereas the free electron laser has already functioned at an average power of 0.36 W. Spectroscopy in the far infrared would be vastly improved by the availability of even 1 W of power. Experiments on semiconductors would have the sensitivity to measure excitonic and impurity spectra. Many transient species occurring in fast reactions or in the stratosphere would become accessible to laboratory infrared spectroscopy, and infrared studies of surfaces would be much extended in their capabilities if the weaker absorbers of radiation could be detected.

If the free electron laser can be further developed to give very high powers approaching the megawatt c.w. range sufficient power would be available to consider photochemical reactions and isotopic separation on an industrial scale. In the laboratory large amounts of radiation could be used to shift populations of states on a macroscopic scale giving rise to non-linear phenomena. But it is probably true that the most valuable uses of such a source are yet to be discovered. □

Correction

In the article 'Multispecific antibodies' (*News and Views* **268,** 689; 1977) column 2, page 690, paragraph 2, line 4 should read: "The 'best' antibodies bind their antigens with avidities of 10^7–10^9 l mol^{-1} but so far multispecificity has only been observed in the $\leqslant 10^6$ l mol^{-1} range."

Planetary crater retention ages

from David W. Hughes

ABSOLUTE ages of planetary features can be determined in principle by dividing the observed crater number density N by the crater production rate, F. So age $= N/F$. William K. Hartmann (Planetary Science Institute, Tuscon, Arizona) is of the opinion that 'the emphasis in funding, research and publication is all on the numerator and none on the denominator' in the above equation. He aims to remedy this state of affairs by his recent paper in *Icarus* (**31,** 260; 1977).

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First let us deal briefly with the numerator. The literature abounds with papers giving details of how N varies with diameter D. Researchers have obtained photographs of lunar and planetary features from Orbiter, Surveyor, Apollo and Mariner spacecraft and have simply counted N, the number of craters per square kilometer with diameters in the range D to $\sqrt{}D$ km. N is proportional to D^n where $n = -2.0$ for lunar maria and the Tharsis plane of Mars, regions where there has been little disturbance. Erosion, which removes smaller craters, gives n values between -1.3 and -1.8. On the slopes of Olympus Mons, the Martian volcano, $n = -2.4$, possibly due to small volcanic pits adding to the impact craters. To give some impressions of the numbers involved, a typical lunar maria which has been exposed to impact bombardment for about 3.4 aeons (an aeon is 10^9 yr) would have about 10,000 craters larger than 1 km in diameter and 10^{13} larger than 10 cm, in an area of 10^6 km^2.

Hartmann deals with F, the crater production rate in considerable detail. F is a function of crater diameter, time from the origin of the Solar System, heliocentric distance and planetary size. The diameter dependence is fairly well understood and a similar power law dependence has been found for crater populations on young undisturbed plains on Mercury, Mars and the Moon. The dependence is consistent with the power law size distribution of asteroids, comets and meteorites, these being the impacting bodies responsible for the craters.

The time dependence is based on Apollo chronologies. F was at least hundreds of times higher than its present value before 4 aeons ago but has been within a factor of 10 of present day values during the past 3 aeons. Most people regard the time dependence as representing a smooth transition from the chaotic state of affairs during planetary accretion to the present day near steady state depletion of the asteroid and comet reservoirs. F would be expected to have roughly the same time dependence for all planets.