into the glomerular filtrate, one would suspect control of some aspect of tubular reabsorption. The obvious first question is its possible role in controlling sodium reabsorption, a subject that is still lost in a haze. But we can all think of many other nephron control functions that we would like to see it perform.

Thus, the importance of the juxtaglomerular complex grows, not merely for control of a single function of the nephron but perhaps and probably as a controller of multiple functions. □

Trouble with time travel

from Paul Davies

SPECULATION about time travel has long been a source of inspiration to science fiction writers and philosophers, but anathema to physicists. Of course, time travel in a limited sense is known to be an observable fact. Ever since the inception of special relativity, with its celebrated time dilation and 'twins' effects, physicists have recognised that a sufficiently powerful rocket would enable an astronaut to travel into the future. By approaching close to the speed of light, a trip which for the astronaut occupies, say, one year, could return him to Earth to find that fifty years had elapsed there. Indeed, the disparity can theoretically be made as great as one pleases by approaching arbitrarily close to the speed of light. The phenomenon is not just a conjecture. Time-travelling subatomic particles are routinely monitored in the laboratory, and the minute, but significant, time dislocations in jet aircraft, have been successfully measured. However, the trip is one way only: there is no going back into the past.

The more entertaining possibility of visiting one's own past is the one that causes physicists headaches, for it plays havoc wtih causality. Suppose a time traveller kills his parents before his birth? Even signalling the past can cause horrendous paradoxes. Consider the machine that destroys itself at two o'clock if it receives a message from itself at one o'clock, sent backwards in time from three o'clock. If it blows up at two, no message goes out at three, so no explosion is ordered.

It could be argued that a mass of contradictions can be avoided if one only allows a limited range of causally self-consistent loops, thus ruling out 'autocidal' machines and so on *ad hoc*. But there is no doubt that the world would be a safer place if some law of physics could be found that forbids travel into the past. The trouble is that, not only do we not know of such a law, we actually do know of some circumstances where our existing theory predicts just such a possibility. The general theory of relativity, which allows space-time to be bent and distorted, describes situations in which world lines (tracks of matter through space-time) are bent right back round and can even 'close up' on themselves, that is, join up with their own past. Thus, a particle can find that its past is also its future—a collapse of causality that few are prepared to take seriously.

One situation in which general relativity seems to predict (if that is the correct word) causality violation is in the vicinity of rapidly rotating massive objects, a celebrated case being the inside of a spinning black hole. Another possibility occurs near a rotating massive cylinder (a more promising case for would-be temponauts). The experts have long regarded mathematical demonstrations of this sort as idealisations, and supposed that in reality some kind of instability would set in to prevent the causality violation occurring. There is still a lack of any comprehensive theorems which will demonstrate that general relativity alone saves itself from its own causality-violating solutions, but in 1976, Frank Tipler of the University of California proved that time machines tend to go hand in hand with space-time singularities, also considered to be extremely unpalatable by physicists. So perhaps ridding the theory of singularities would also save causality.

A different possibility has recently been explored by an undergraduate student from Bristol University, now a postgraduate at King's College, London. Writing in a recent issue of the *Journal of Physics* (Charlton, *J. Phys.* **11**, 2207; 1978) he first investigates the topology of the two-dimensional surface which surrounds the region of spacetime in which particles possess closed timelike world lines, proving it is always a torus. He then goes on to discuss the behaviour of photons close to the time machine region. The result which he finds is that the angular momentum carried by the photon rises without limit as the conditions are approached for the existence of causality violation. In physical terms this means that any loss of radiation from the region will transport vast quantities of angular momentum away from the rotating body. The reaction back on the body itself will cause it to spin down, and hence retreat from the threat of causality violation. Thus, there seems to be an inbuilt mechanism to prevent real objects from rotating fast enough to allow time travel.

Just how general Charlton's mechanism will turn out to be is not yet clear, but it does go some way to confirm what has long been suspected—that travel into the past is purely a fiction. □

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Lunar origin and palaeotides

from David W. Hughes

BEFORE the Apollo missions to the Moon there were three seriously held hypotheses for its origin. The earliest is just over a hundred years old. George H. Darwin suggested in 1878 that in early times part of the Earth's crust broke away to produce the Moon, leaving the Pacific Ocean as a scar. This occurred when the Earth had already differentiated into a core and a mantle and was rotating with a period of ~ 4 h. This low spin period caused it to become oblate and unstable. More recent additions to this hypothesis suggest that Mars and a myriad of smaller bodies broke away at the same time.

The second hypothesis proposes that the Moon was formed as an independent Solar System planet, further away from the Sun than Earth, and was captured by Earth about 4×10^9 yr ago.

Ring accretion is the basis of the third hypothesis. Earth once had a ring system that may have resembled that of Saturn, the planetesimals within the rings either being derived from Earth by silicate precipitation in a massive high temperature atmosphere or being the remnants of the original condensing planetesimal group that formed the Earth. This ring coagulated after it had receded beyond the Roche limit.

Following N. M. Short (*Planetary Geology*, Prentice Hall, 1975) we can list some of the important lunar characteristics that the origin hypotheses have to explain. The Moon is very close to being a homogeneous sphere; it has a lower density than Earth, indicating that it has lost iron; there is no water and fewer volatile and siderophile elements than both the Earth and chondritic meteorites, the Moon seems to be enriched in refractory elements, and obviously has a none too primitive composition; it was formed about 4.6×10^9 yr ago, the highland rocks being about 4.3×10^9 to 4.1×10^9 yr old, the mare basalts being about 3.7×10^9 yr old. It seems that the Moon was formed essentially at the same time as Earth and that the majority of the surface evolution took place in the

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0028–0836/79/0277—0602$01.00