different bone mass, such as African–Americans, Mexican–Americans and Orientals. The allelic change in the vitamin D receptor is simple and unambiguous, and should be relatively easy to examine in other population groups. Second, more studies are needed to show if this polymorphism results in alterations of receptor action, a necessary prerequisite for a direct functional link between the observed polymorphism in the gene and peak bone mass. A preliminary experiment described in the paper[1] shows an increase in luciferase activity when this reporter gene is linked to the 3′ untranslated region of the vitamin D receptor, suggesting it is directly responsible for the functional change. Even more helpful would be the demonstration that administration of vitamin D to individuals with unfavourable alleles has a demonstrable difference in response parameters compared with similar treatment in individuals with different allelic patterns.

If these associations of bone mass with the vitamin D receptor gene hold up, then the implications are considerable. The place for biologically active forms of vitamin D in treatment of osteoporosis is controversial, some studies indicating no beneficial effect[7], but others pointing to an increase in bone mineral density and reduction in vertebral fractures in patients with established disease[8,9], particularly when used in larger (and potentially more toxic) doses. Treatment with small doses of vitamin D and calcium has recently been shown to decrease rates of hip fracture in elderly patients[10]. If the vitamin D receptor gene determines bone mass, there might be little point in beginning treatment with vitamin D metabolites after bone mass has irreversibly declined, because of the effects of multiple non-genetic factors. On the other hand, 1,25 dihydroxyvitamin D treatment may be most effective in optimizing bone mass when used earlier in life in patients with unfavourable vitamin D receptor alleles.

The implications for research into the physiological effects of vitamin D on bone may be equally interesting. The active metabolites of vitamin D have myriad effects *in vitro* on cells in both the osteoclast and osteoblast lineages, as well as on other cells in the bone microenvironment including lymphocytes, monocytes and macrophages. There are many potential mechanisms by which the vitamin D receptor could influence the delicate relationship between osteoclasts and osteoblasts which bone biologists will need to unravel. The vitamin D receptor is a transcription factor which forms homodimers or heterodimers with other members of the steroid hormone receptor superfamily (most notably, the retinoic acid receptor RXR)[11], so several signalling pathways may mediate effects on gene expression.

At the very least, this report of potential functional allelic changes in the vitamin D receptor gene is highly provocative. Whether or not it is confirmed, it will no doubt prompt other studies on the mechanisms responsible for the unquestionably important genetic influence on bone mass. □

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INERTIAL FUSION

Rayleigh's challenge endures

Richard D. Petrasso

AMIDST the news of the results[1] from the Princeton tokamak fusion reactor, we should not forget the other runner in the race to achieve practical fusion power. At an international conference on plasma physics last year*, the consensus was that an instability first recognized by Lord Rayleigh last century remains one of the most challenging problems in the field of inertial confinement fusion (ICF).

Lord Rayleigh, his interest sparked by experiments on cirrus cloud formation, derived in 1880 the properties of an interface instability that occurs when a dense fluid is supported by a lighter one[2]. Invert a glass of water and this instability occurs — the dense water falls out even though, in a carefully prepared experiment, the air pressure is more than sufficient to support the water[3]. As the effects of gravity are, by the equivalence principle of general relativity, tantamount to acceleration in the opposite direction, the instability will also occur whenever a light fluid pushes against a dense one, as, for example, in supernovae explosions[4], magnetically confined plasmas[5] and heavy-nuclei collisions[6]. In the spectacular instance of supernova SN1987A, the unexpectedly early appearance of energetic γ-rays, following the rebound of the collapsed stellar core, was explained by long, dense fingers of radioactive ^{56}Co piercing the turbid blanket of tenuous gas that enveloped it and retarded its outward expansion[4].

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Lord Rayleigh — legacy of instability.

Plasma physicists grappling with the process of inertial confinement fusion have focused their attention on this interface instability for the past decade, and are now making substantial progress. In the ICF approach, a small quantity of fusion fuel (consisting of the hydrogen isotopes of deuterium and tritium) is to be imploded and compressed in about 10^{-8} s by ablating (that is, explosively evaporating) a thin, dense, spherical shell that surrounds the fuel. Before compression, the sphere radius and the shell thickness are about 2 mm and 0.2 mm, respectively. At the moment of peak compression, when the sphere radius is smaller by a factor of 20 and the fuel density is 1,000 times that of solid deuterium, the deuterium–tritium fuel, which is heated by compressional work, ignites and releases around 500 MJ of fusion energy (equivalent to 3.5 gallons of oil). But the

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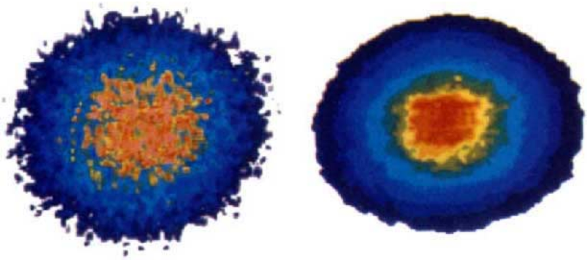
spherical ablating surface is unquestionably vulnerable to this interface instability, and the most urgent issue is whether sufficient fuel compression will occur before the instability dismantles the ablating shell, mixing it with the heated fuel[7,8].

During the Manhattan Project in the Second World War, Geoffrey Taylor looked at the analogous consequences of this interface instability for the implosion dynamics of the atomic bomb (refs 9, 10; and P. Morrison, personal communication). Thereafter, the instability was referred to as the Rayleigh–Taylor (RT). With the colossal differences in scale and design, and the use of highly reactive fissile material (^{235}U and ^{239}Pu), however, the instability is much less of a problem for an atomic weapon than for ICF.



The effects of beam smoothing are dramatically evident in these cross-sectional images of a laser beam: left, without smoothing; right, with smoothing (J. Knauer, University of Rochester). Without smoothing, the laser beam can seed and then drive the Rayleigh–Taylor instability, which, for fusion capsules, would thwart adequate fuel compression.

Our present understanding is that if the instability grows unabated at the Rayleigh rate, then adequate fuel compression cannot be achieved and the ICF concept will fail (J. Kilkenny, Lawrence Livermore National Laboratory (LLNL)). Rayleigh's rate, γ_{R}, is $(2\pi g/\lambda)^{0.5}$, where g is the acceleration at the ablation front, and λ is the wavelength of the perturbation. Fortunately, the dynamics of plasma flowing outward across the ablation front reduce the instability growth rate from Rayleigh's value[11,12]. The consequences of this ablative stabilization, plus other secondary ameliorations, are often expressed as a reduced growth rate $\gamma = \epsilon\gamma_{\mathrm{R}}$, where ϵ is less than 1 and is a function of λ (K. Nishihara, Osaka University). The most unstable λ is of the order of the shell thickness.

In the linear regime, the size of the instability is well described by $a_0 \exp(\epsilon\gamma_{\mathrm{R}}t)$, where a_0 is the amplitude of the initial perturbation, and t is time. Because of exponential growth (a valid model until the instability size is of order $\lambda/10$), even a small reduction in the growth rate can have dramatic consequences. Efforts to control the RT instability have in part focused on making surface imperfections as small as possible ($a_0 \sim 250$ Å) so that meaningful measurements of ϵ can be inferred during the linear phase. In fact by the time $\epsilon\gamma_{\mathrm{R}}t \sim 6$, three-dimensional calculations show that nonlinear effects generate and couple together different modes (J. Dahlburg, Naval Research Laboratory). This coupling between λ and its harmonics coincides with the dismantling of the ablation shell.

Parallel advances in laser-beam smoothing techniques[8,13–15] are reducing nonuniformities in the laser irradiance which would otherwise create large initial perturbations from which the RT instability would spring. (In addition, these laser nonuniformities drive a different class of undesirable instabilities known as laser–plasma or parametric instabilities; R. Berger, LLNL). Carefully controlled experiments are in progress in which various levels of laser-beam smoothing are used on one arm of the NOVA glass laser (S. Glendinning, LLNL). For the KrF gas laser at the Naval Research Laboratory, root-mean-square nonuniformities in a single laser beam are about 1.6 per cent (T. Lehecka, Science Applications International Corporation). When the system is fully operational with all 44 independent, overlapping beams, r.m.s. nonuniformity of about 0.25 per cent $(1.6/\sqrt{44})$ is expected, which is comparable to surface imperfections of ~ 200 Å. Another promising line is to generate, through an X-ray flash, a uniform plasma around the ablator, which should further reduce laser imprinting (R. S. Craxton, University of Rochester; O. Willi, Imperial College London).

With high levels of laser smoothing on NOVA, the effects of deliberately introduced initial perturbations can be seen (J. Knauer, University of Rochester). A low-Z (low mass number) plastic target was prepared with a perturbation of 30 μm wavelength (λ) and 0.25 μm amplitude (a_0). On irradiation, ϵ of about 0.65 was achieved when the hydrogen/carbon plastic was lightly doped with 6 per cent of chlorine. The desirable effects of the chlorine were manifested by an increase in the ablation rate and, secondarily, by an increase in the density scale length at the ablation front (according to theory, this increase should be beneficial; R. Betti, University of Rochester). But this doping procedure involves a delicate balance: premature heating of the fuel from the chlorine X-rays means that more laser energy is required to compress the fuel. This degrades the figure-of-merit known as the fusion gain (G), which is the ratio of fusion to laser energy, and which must be at least 30 for just-plausible designs of future ICF reactors (C. Verdon, University of Rochester).

In a different approach to achieving compression while minimizing the RT instability, either lasers (A. Hauer, Los Alamos National Laboratory) or particle beams (J. Quintenz, Sandia National Laboratory) can be used to generate X-rays that flood the interior of a cavity called a hohlraum[7,8]. In turn these X-rays irradiate the ablator. (In the lexicon of the field, this is known as 'indirect drive', in contrast to 'direct drive' in which lasers directly irradiate the ablator.) In the X-ray drive experiments at LLNL, values of $\epsilon \approx 0.5$ were achieved for wavelength perturbations of around 50 μm (Kilkenny; B. Remington, LLNL). These low values of ϵ result from the deep penetration of the X-rays into the ablator, increasing the plasma ablation rate.

Encouraging progress has been made in ameliorating the RT instability during the acceleration phase of the compression. But it is a herculean task: for like Hydra, the instability rears an ugly head elsewhere, this time just inside the sphere at the fuel–shell interface. During the final deceleration stage to peak compression, the less dense deuterium–tritium fuel now pushes vigorously against the denser shell, which is still inwardly imploding. Just as in supernova SN1987A, these conditions are ripe for the RT instability. But whereas in the acceleration phase the stabilizing effects of ablation reduced the growth to less than the Rayleigh value, now the full force of the instability takes hold. Still, there is reason for optimism as its onset at the fuel–shell interface commences only in the very last moments of compression. The vexing question is, will the shell remain sufficiently intact or will spikes of it penetrate and mix into the fuel, diluting its potency and subverting the fusion gain? In the near future, an upgraded laser facility (T. Boehly, University of Rochester) and new experiments (O. Landen, LLNL) will test this next interface for the effects of the irrepressible Rayleigh–Taylor instability. □

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