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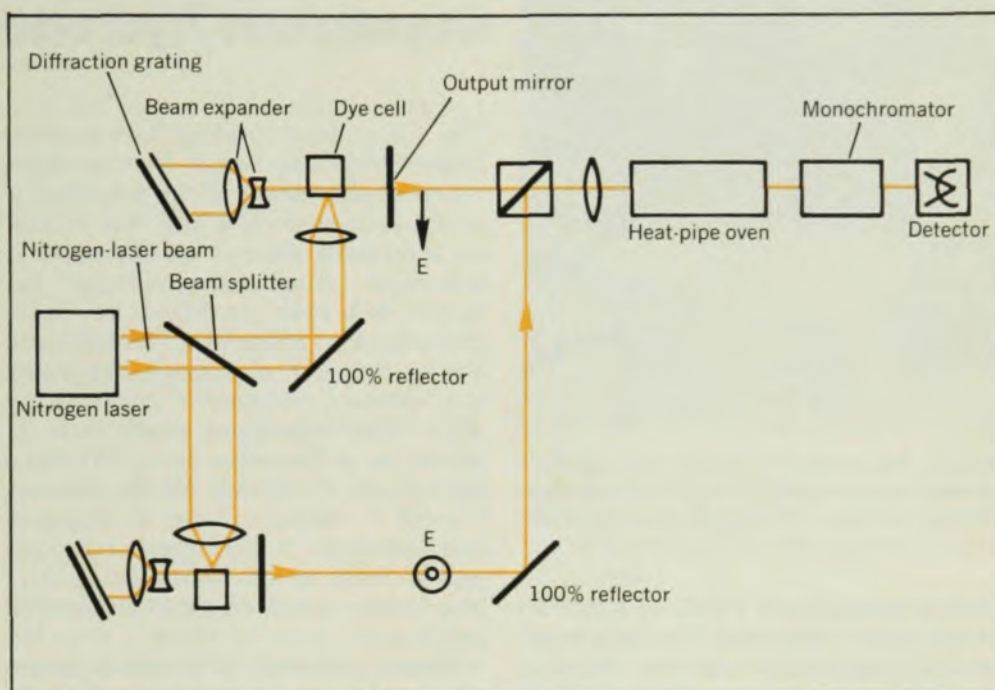
Tunable coherent infrared techniques show progress

Recently several groups have produced tunable coherent infrared sources; some of these sources are tunable over a broad range of wavelengths. They vary in their ability to be continuously tuned. The most novel of these sources was reported by James J. Wynne in an invited paper at the Washington meeting of the American Physical Society on 23 April. Wynne, Peter Sorokin and John Lankard, all of IBM Research Center, reported¹ that they had produced a continuously tunable source over the range 2-24 microns with no apparent fundamental limitation to achieving longer-wavelength generation. Groups at MIT National Magnet Laboratory, Bell Laboratories, Rice University and the University of California at Berkeley have all recently reported on tunable coherent infrared sources.

These sources have many applications. They can be used to study elementary excitations in solids and complex biological molecules. A number of air pollutants show strong absorption in the infrared. It has been suggested that because molecules of different isotopes of the same element have different vibrational frequencies, one could achieve efficient and economical separation of these isotopes. For astronomy the sources could be used as a tunable local oscillator in a heterodyne system.

In the IBM experiment beams from two separate dye lasers, which are pumped simultaneously by a nitrogen laser, interact within a chamber of alkali vapor, the vapor being maintained in a heat-pipe oven. Each dye laser can be tuned from about 0.36 to 0.7 microns by using different dyes and diffraction gratings. The experimenters used a "four-wave parametric" conversion technique (see figure on page 20). Most of the work was done with potassium. The first dye laser is chosen so that its output wavelength is tunable in the neighborhood of the 4s-5p resonance lines of potassium. The beam does three things: It provides one of the waves needed in the four-wave mixing process; it generates a second wave needed for the four-wave process by inducing stimulated electronic Raman emission and producing a Stokes wave at a frequency $\nu_S = \nu_L - E(5s)/h$ it allows the four-wave mixing process to become phase matched through fine adjustments of its frequency.

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Tunable coherent infrared source has two dye lasers pumped by a nitrogen laser. The beams interact within a chamber of alkali vapor. The dye lasers are tunable by using different dyes and diffraction gratings. The source is tunable from 2-24 microns.

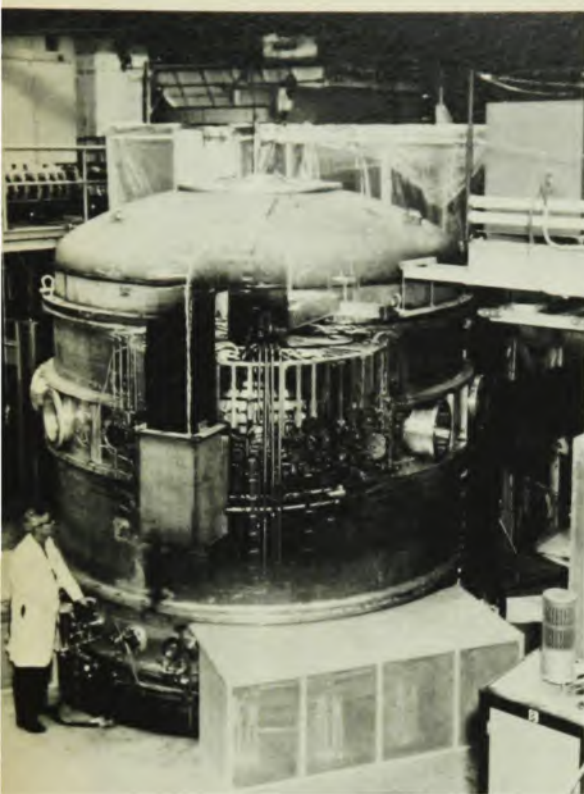
Ormak nears collisionless regime

The Ormak experiment at Oak Ridge National Laboratory has advanced appreciably toward the so-called collisionless regime in studies that increase the expectation for reaching the "reactor regime" without damaging loss from instabilities. Plasma ions have travelled about five to ten times around the torus before scattering 90 deg, and no new anomalous effects were observed. The result gives increased confidence that no additional empirical components are needed to explain the scaling of ion temperature in this regime, that the same combination of the classical laws of atomic and plasma physics plus empiricism (pseudoclassical scaling) hold true here as in previous experiments. Ormak was able to reach a higher degree of collisionlessness, although the ion temperatures reached did not necessarily exceed temperatures reached in some other experiments, because of its fat-doughnut geometry. These results were described at the March meeting on toroidal plasma confinement in Garching, Germany.

Ormak is a toroidal ohmically heated

confinement device with a low aspect ratio: The ratio of major radius (79.5 cm) to minor radius (23.5 cm) is only 3.4. A set of 56 equally spaced copper coils can supply a maximum toroidal field of 25 kG to confine the plasma, and the maximum peak plasma current is about 400 kA. The reported studies were done over a range of experimental parameters; for example, a typical study was done at 18-kG toroidal field, and a plasma current of 120 kA had an ion temperature of 350 eV, a 800-eV electron temperature, a peak electron density n of $5 \times 10^{13} \text{ cm}^{-3}$ and a confinement time τ of 15 milli-sec. Among the diagnostic tools that were used to analyze the plasma parameters were Thomson scattering (electron-energy profiles), charge exchange (ion temperatures) diamagnetic loops (changes in plasma pressure), soft x rays (peak electron temperature) and microwave interferometry (average electron density).

Deep penetration into the collisionless regime is considered an important feasibility test for toroidal confinement systems: In a reactor, the mean free



Ormak, the ohmically heated toroidal confinement device at Oak Ridge National Laboratory, is seen in this double exposure.

path of plasma ions would be about 30 or 40 times the torus circumference. In this experiment the ion collision frequency was low enough that diffusive losses from thermal conductivity were relatively unimportant and other loss mechanisms, such as charge exchange, could be studied. The Ormak geometry—a fat rather than a thin doughnut—maximized the path length of the ions with respect to the size of the so-called “banana” orbits. These banana-shaped orbits might, according to theoretical calculations for the collisionless regime, lead to trapped-particle instabilities, but no evidence of enhanced losses due to these instabilities was observed. As Herman Postma, head of the ORNL thermonuclear division, and George Kelley, director of the Ormak project, explained to us, they are still far from the Lawson criterion range, which is the $n\tau$ range for an operating reactor, but with some modifications now underway they feel able to confront some of the physics that would be important in the reactor regime.

Injection heating. The next step at Ormak is to use neutral-beam injection heating to raise the temperatures still higher—to about 1 keV—and penetrate further into the collisionless regime. Beams of very energetic neutral particles (hydrogen atoms at 12.5 keV and 25 keV) are added from the outside, and these particles transfer their energy to the plasma particles, raising the bulk temperature beyond what ohmic heating can do. Recent results at the Princeton Adiabatic Toroidal Com-

pressor showed compressive heating to be a useful booster for ohmic heating (see *PHYSICS TODAY*, January, page 17), and the Princeton group now is preparing to combine the compression and injection techniques.

Ormak is now in a shutdown period, so that the injection heaters can be added, and Postma tells us that the project should be at the data-taking

stage again by the end of the summer. He points out that injection heating will also provide a simulation of the energetic alpha particles ($4\frac{1}{2}$ MeV) produced in a self-sustaining reactor—the particles that must heat the fusion plasma by transferring their energy to it. The next set of experiments should give some answers on how well this transfer takes place. —MSR

Copernicus hydrogen data confirm theory

The Copernicus Orbiting Astronomical Observatory has found that in some stellar clouds much of the hydrogen is in the molecular state and that in others essentially none of the hydrogen is molecular. Such “all-or-nothing” behavior had been predicted by David Hollenbach, Michael Werner and Edwin Salpeter of Cornell University in a detailed calculation¹ published in 1971. The Copernicus results were reported by a Princeton group² (Lyman Spitzer, J. F. Drake, E. B. Jenkins, Donald C. Morton, John B. Rogerson and Donald G. York) in one of five papers on OAO results appearing in the 1 May issue of *Astrophysical Journal Letters*.

Theory. Usually it is atomic hydrogen that is seen in an astronomical situation because its lines are visible from the ground, either in visible light or in radio waves at 21-cm wavelength. However, several people had discussed the possibility of molecular hydrogen, including H. C. van de Hulst (Leiden Observatory), Thomas Gold (Cornell), and George Field, W. B. Somerville and Kurt Dressler (then at Princeton).

In 1967 Theodore Stecher and D. A. Williams (Goddard Space Flight Center) verified theoretically a mechanism (suggested by Philip Solomon) that destroys molecular hydrogen. Unlike the usual kind of photodissociation, in which any photon with energy greater than a certain threshold will break the molecule apart, in the new process the molecules could be disrupted only by the absorption of light in the Lyman band—the molecule would be excited to an excited level and then a certain percentage would drop down to the continuum in the vibrational level. Stecher and Williams estimated that about 10% of the line absorption would produce dissociation in this way. They pointed out that because of this dissociation the ratio of molecular to atomic hydrogen should be very small—of the order of 10^{-7} .

In their paper two years ago Hollenbach, Werner and Salpeter made a detailed calculation, asking what would happen in interstellar clouds of different thicknesses. If a cloud is not very

thick then photons with the Stecher-Williams mechanism will break up the hydrogen molecules so efficiently that only a very insignificant part of the hydrogen in such a cloud would be molecular.

However, because it is only line radiation that breaks up the molecules, some self-shielding occurs. If the cloud is thick enough, then it is the hydrogen itself that filters out these photons. The ultraviolet radiation from the star would be absorbed in the dense cloud on the outer edges, and in the center of the dense cloud there would be no ultraviolet radiation. Then the cloud would have almost all molecular hydrogen. Salpeter describes the two possibilities as “all or nothing.”

To form the molecular hydrogen, the Cornell theorists argued that two hydrogen atoms would separately hit a dust grain, wander around the surface, stick onto impurity states, meet each other and finally form a molecule. The Cornell group then computed in detail the transfer of radiation in the cloud and found the percentage of atomic and molecular hydrogen as a function of distance in the cloud. They found that for typical densities, the switch over from molecular to atomic hydrogen would be roughly where the optical depth in visible light was about half a magnitude. Salpeter told us that very qualitatively Copernicus results agree with this prediction.

Observations. In 1970 George Carruthers of the Naval Research Laboratory did a rocket measurement³ of some ultraviolet lines in two stars. There were indications of the all-or-nothing effect, one star (Xi Persei) having about 40% of the interstellar hydrogen in molecular form and the other apparently having much less or none. Andrew M. Smith (Goddard Space Flight Center) recently also found this all-or-nothing effect.

The Copernicus experiment uses an ultraviolet spectrometer to analyze the light from bright stars, down to fifth or sixth magnitude.

Reddened stars have a color excess because they are behind an obscuring cloud. This color excess is proportion-