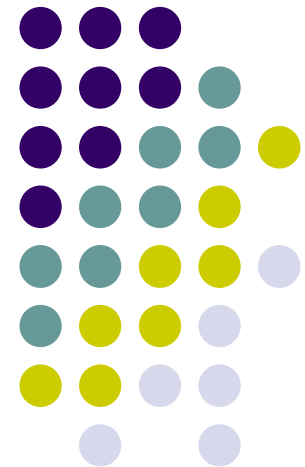


Journal Club

Oct 14th /2004

Superflow in Solid Helium





Today's Paper

SCIENCE VOL 305 24 SEPTEMBER 2004

Observation of Superflow in Solid Helium

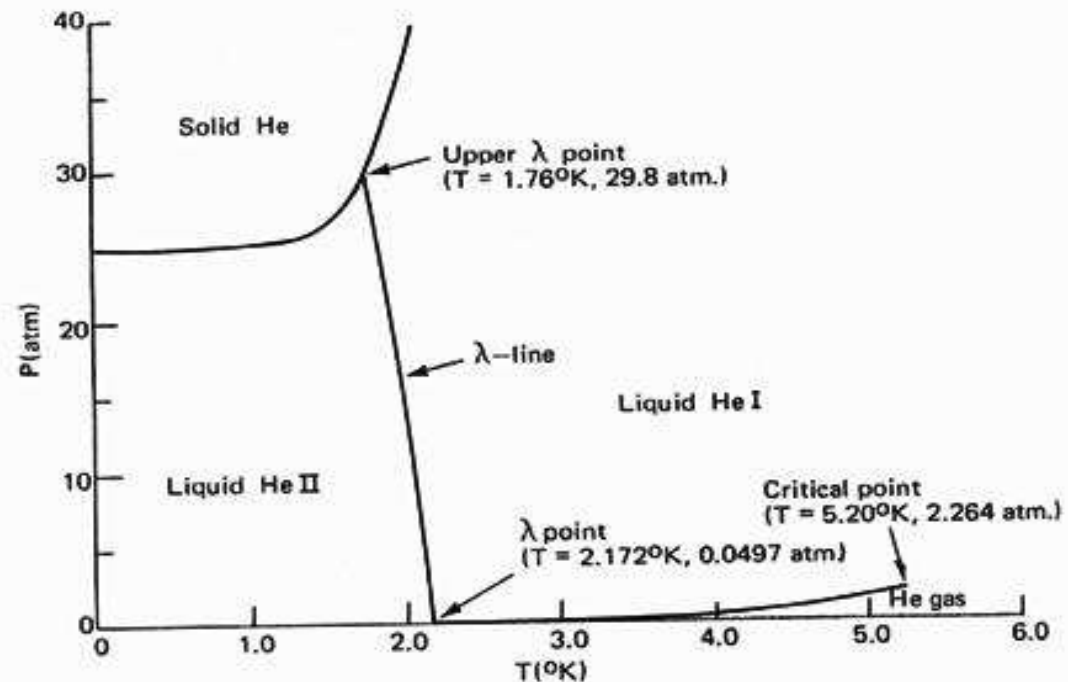
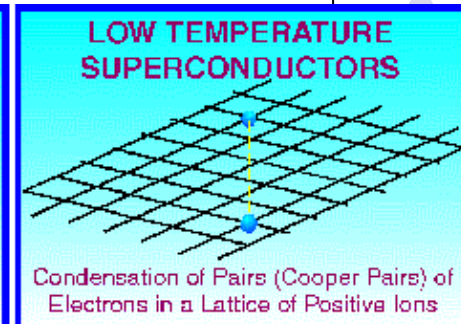
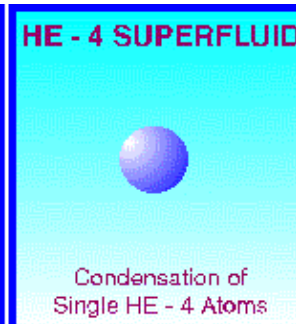
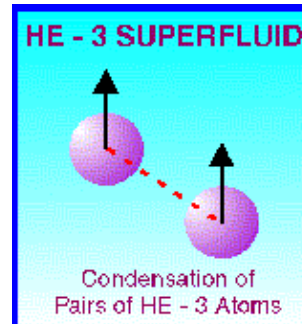
E. Kim and M. H. W. Chan*

We report on the observation of nonclassical rotational inertia in solid helium-4 confined to an annular channel in a sample cell under torsional motion, demonstrating superfluid behavior. The effect shows up as a drop in the resonant oscillation period as the sample cell is cooled below 230 millikelvin. Measurement of 17 solid samples allows us to map out the boundary of this superfluid-like solid or supersolid phase from the melting line up to 66 bars. This experiment indicates that superfluid behavior is found in all three phases of matter.

Department of Physics, Pennsylvania State University,
University Park, PA 16802, USA.

Background: Superfluid ^4He

- He-4 (“boson”)
- Superfluid at $T=2.14\text{K}$ (Landau, 1962)
- Quantum phenomena (similar to superconductivity) \rightarrow Macroscopic quantum state (BEC forms)
- 1967 – Superfluid ^3He at $\sim 2\text{mK}$ (!) \rightarrow Nobel Prizes awarded to D. M. Lee and R. C. Richardson (experiment) in 1996 and to Tony Legget (theory) in 2003



The phase diagram of He^4 .

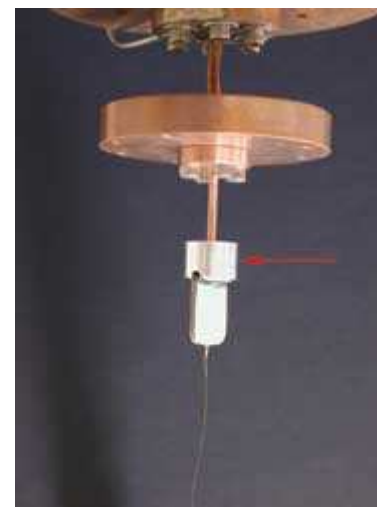
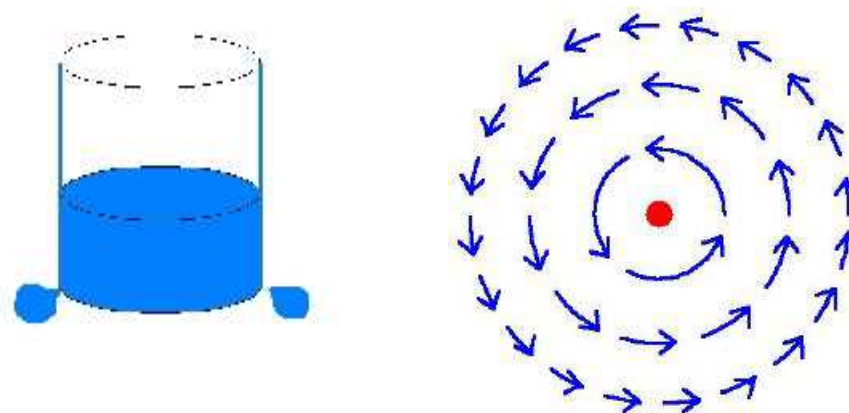


Background: Superfluid ^4He

- Interesting phenomena: Zero viscosity flow, film flow, quantized vortices and Non-Classical Rotational Inertia (NCRI).
- In this last case, when the fluid is rotated below T_c and with $\omega < \omega_c$, the moment of inertia decreases from the classical value by

$$I(T) = I_{\text{classical}}[1 - f_s(T)]$$

$f_s(T) \rightarrow 1$ as $T \rightarrow 0$ is the “superfluid fraction”.





“Supersolid” ^4He ????

VOLUME 25, NUMBER 22

PHYSICAL REVIEW LETTERS

30 NOVEMBER 1970

Can a Solid Be “Superfluid”?

A. J. Leggett

School of Mathematical and Physical Sciences, University of Sussex, Falmer, Brighton, Sussex, England

(Received 15 September 1970)

It is suggested that the property of nonclassical rotational inertia possessed by superfluid liquid helium may be shared by some solids. In particular, nonclassical rotational inertia very probably occurs if the solid is Bose-condensed as recently proposed by Chester. Anomalous macroscopic effects are then predicted. However, the associated superfluid fraction is shown to be very small (probably $\lesssim 10^{-4}$) even at $T=0$, so that these effects could well have been missed. Direct tests are proposed.



“Supersolid” ^4He ????

news and views

Condensed-matter physics

Probable observation of a supersolid helium phase

E. Kim & M. H. W. Chan

Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA

When liquid ^4He is cooled below 2.176 K, it undergoes a phase transition—Bose–Einstein condensation—and becomes a superfluid with zero viscosity¹. Once in such a state, it can flow without dissipation even through pores of atomic dimensions. Although it is intuitive to associate superflow only with the liquid phase², it has been proposed theoretically^{3–5} that superflow can also occur in the solid phase of ^4He . Owing to quantum mechanical fluctuations, delocalized vacancies and defects are expected to be present in crystalline solid ^4He , even in the limit of zero temperature. These zero-point vacancies can in principle allow the appearance of superfluidity in the solid^{3,4}. However, in spite of many attempts⁶, such a ‘supersolid’ phase has yet to be observed in bulk solid ^4He . Here we report torsional oscillator measurements on solid helium confined in a porous medium, a configuration that is likely to be more heavily populated with vacancies than bulk helium. We find an abrupt drop in the rotational inertia⁵ of the confined solid below a certain critical temperature. The most likely interpretation of the inertia drop is entry into the supersolid phase. If confirmed, our results show that all three states of matter—gas⁷, liquid¹ and solid—can undergo Bose–Einstein condensation.

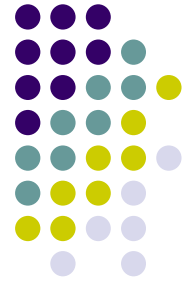
Supersolid helium

John Beamish

Superfluids flow without resistance. It’s hard to imagine, but quantum mechanically possible, that solids should do the same at low enough temperatures. Helium-4 might be the first known ‘supersolid’.

BUT...

“Anthony J. Leggett of the University of Illinois at Urbana-Champaign, one of the first theorists to propose supersolidity, **doubts that Chan and Kim have uncovered the supersolidity that he and other theorists have envisioned.** After all, he notes, helium frozen within **glass pores** differs markedly from the bulk crystals to which the theories apply. Instead, he speculates that the scientists have detected some other type of superfluid behavior.”



Today's Paper

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Observation of Superflow in Solid Helium

E. Kim and M. H. W. Chan*

We report on the observation of nonclassical rotational inertia in solid helium-4 confined to an annular channel in a sample cell under torsional motion, demonstrating superfluid behavior. The effect shows up as a drop in the resonant oscillation period as the sample cell is cooled below 230 millikelvin. Measurement of 17 solid samples allows us to map out the boundary of this superfluid-like solid or supersolid phase from the melting line up to 66 bars. This experiment indicates that superfluid behavior is found in all three phases of matter.

Department of Physics, Pennsylvania State University,
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Today's Paper: the comment.

SCIENCE VOL 305 24 SEPTEMBER 2004



Superfluidity in a Crystal?

Tony Leggett

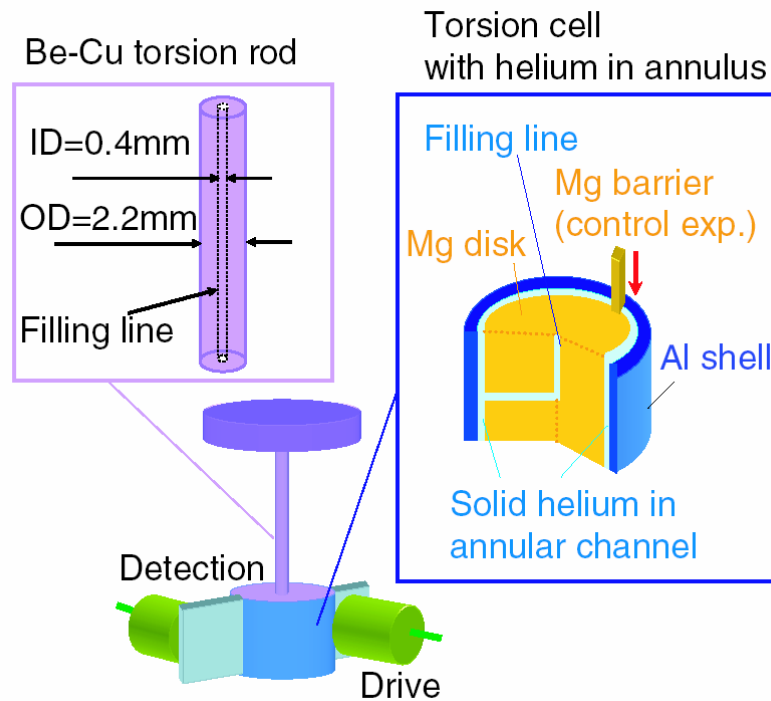
Imagine that you place a small solid body—say, a coin—on the axis of an old-fashioned gramophone turntable, and set the latter into slow rotation. You would expect the coin to rotate with the turntable. But it will not do so if it is made of solid ^4He , according to Kim and Chan (see report in this week's issue on page 1941) (*1*).

(...)

(...) This last scenario—which prior to the experiment of Kim and Chan would probably have been dismissed as implausible by the vast majority of workers in the field—raises a number of theoretical issues, including the question whether BEC is a necessary condition for NCRI in a bulk three-dimensional system such as helium. In any case, if the interpretation Kim and Chan give of their raw data is correct (and quite probably even if it is not!), their experiment will force theorists to revise dramatically the generally accepted picture of crystalline solid ^4He .



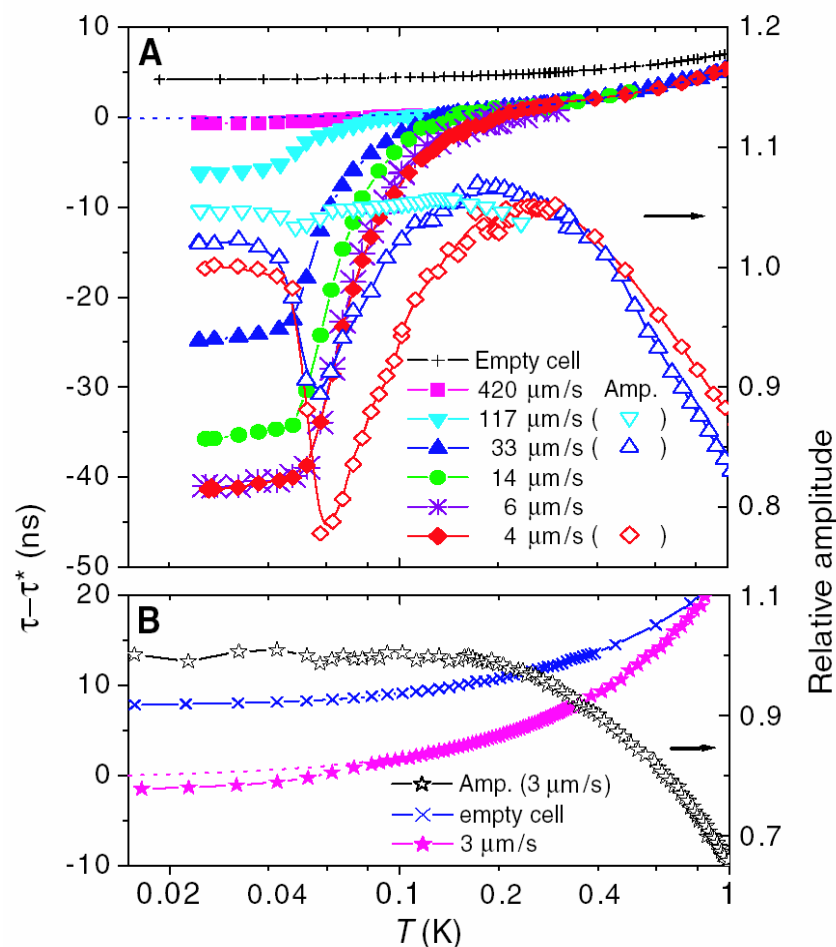
The experiment:



- High pressure, low T (in order to make sure the Helim is solid)
- Measure the resonance period $\tau^* = 2\pi\sqrt{I/k}$



The experiment: Results



$$\tau^* = 2\pi\sqrt{I/k} \quad \omega < \omega^*$$

Fig. 2. Resonant period and amplitude of oscillation as a function of temperature for the unblocked (A) and blocked (B) cell. The period readings are shifted relative to τ^* , the resonant period at 300 mK. The values of τ^* for the open cell with helium are 1,099,477 ns, 1,099,480 ns, 1,099,482 ns, 1,099,483 ns, 1,099,488 ns, and 1,099,485 ns when the maximum oscillation speed are, respectively, 4, 6, 14, 33, 117, and 420 $\mu\text{m/s}$. The empty-cell period at 300 mK is 1,096,465 ns, 3012 ns less than that when the cell is full. The value of τ^* for the blocked cell with solid helium at 36 bars at 300 mK is 2,242,940 ns. The resonant period when it is empty at 300 mK is 2,235,890 ns.

The experiment: Results

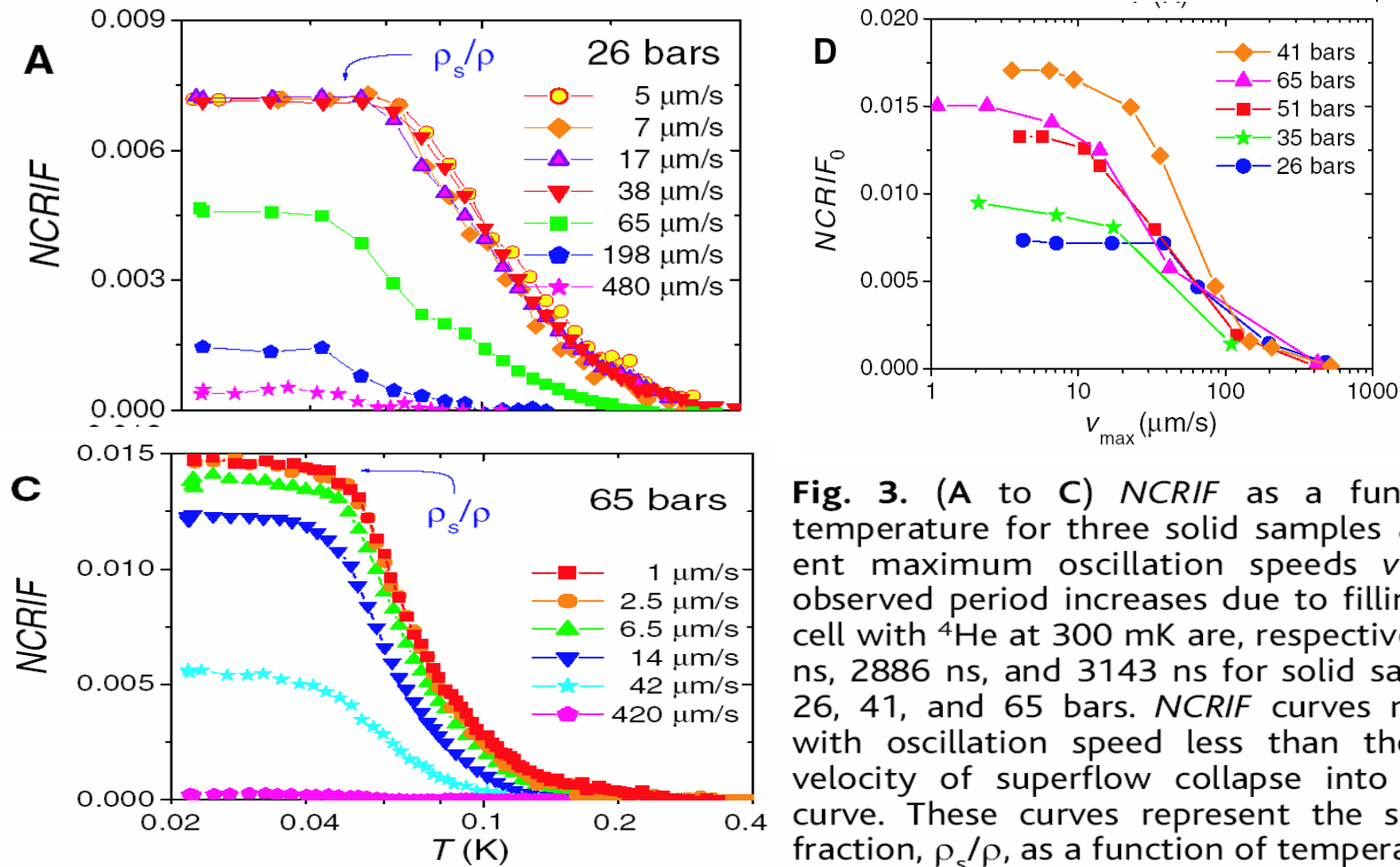


Fig. 3. (A to C) $NCRIF$ as a function of temperature for three solid samples at different maximum oscillation speeds v_{max} . The observed period increases due to filling of the cell with ^4He at 300 mK are, respectively, 2785 ns, 2886 ns, and 3143 ns for solid samples at 26, 41, and 65 bars. $NCRIF$ curves measured with oscillation speed less than the critical velocity of superflow collapse into a single curve. These curves represent the supersolid fraction, ρ_s/ρ , as a function of temperature. (D) $NCRIF$ in the low-temperature limit as a function of v_{max} .

$$I(T) = I_{\text{classical}}[1 - f_s(T)] \quad f_s(T) = \rho_s / \rho$$



The experiment: Results

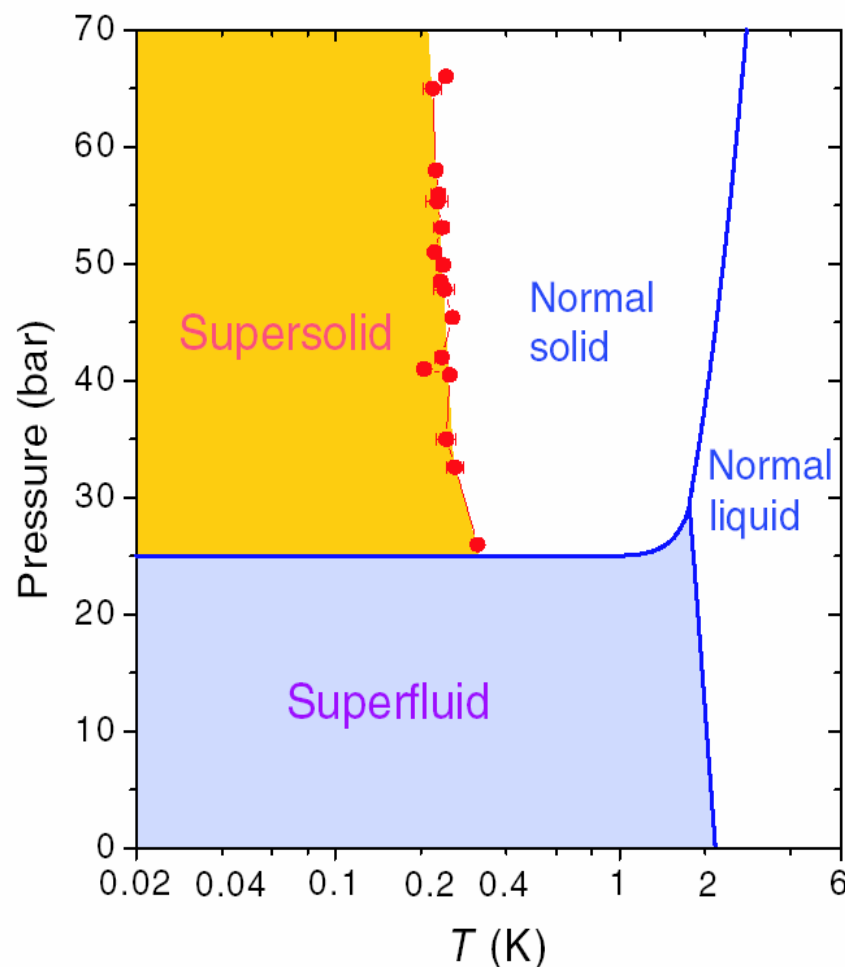


Fig. 4. Phase diagram of liquid and solid helium.

The smooth decay in ρ_s/ρ with increasing temperature near 250 mK makes it difficult to determine with precision the supersolid transition temperature T_c . We estimate the value of T_c by assuming a linear dependence of ρ_s/ρ on temperature near T_c and then use the data with ρ_s/ρ between 0.01 and 0.1 to fit for T_c . The resultant transition temperatures, with uncertainty of 20 mK, are likely to be lower than the “true” values. The transition temperatures we have found show a weak pressure dependence decreasing from 315 mK at 26 bars down to 230 mK at pressures exceeding 40 bars. The phase diagram of ^4He , including both the superfluid and supersolid phases, is shown in Fig. 4.

Conclusions: Why is it a *Science* paper?



- NCRI in solid ^4He with $f_s \sim 1.7\%$. If correct, “the implications are revolutionary”, according to Leggett.
 - It’s a crystalline solid. Is there some sort of BEC there?
 - “Zero-Point Vacancy” Bose-Einstein Condensation if $N_{\text{atoms}} < N_{\text{sites}}$?
 - Is it a metastable phase of some sort?
 - If $N_{\text{atoms}} = N_{\text{sites}}$, could exchange processes display NCRI?
- The current picture of solid ^4He will have to be “dramatically revised”.
- *Hope I could answer at least $\frac{1}{2}$ of Nancy’s questions... 😊*