

# QUANTUM TALES GRAPHENE, 2004

A. GEIM



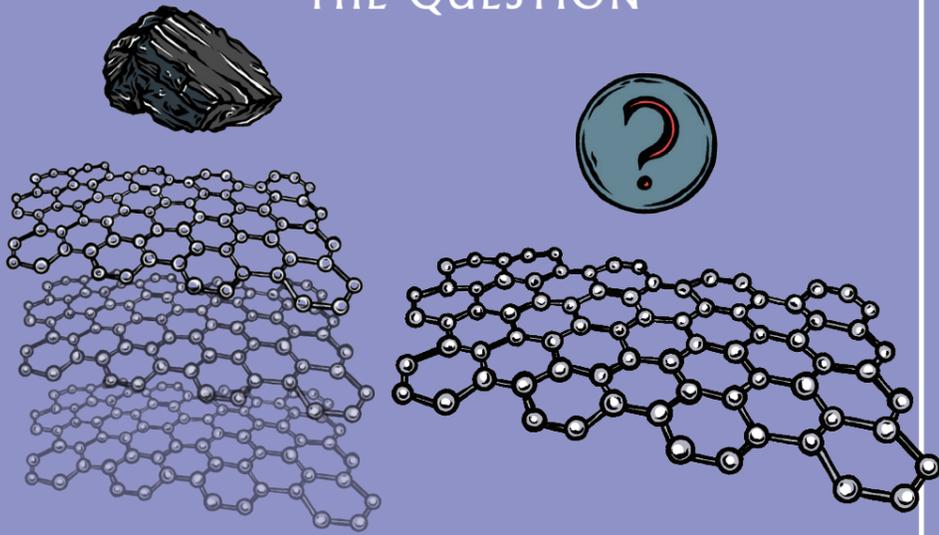
K. NOVOSELOV



MANCHESTER UNIVERSITY, GB

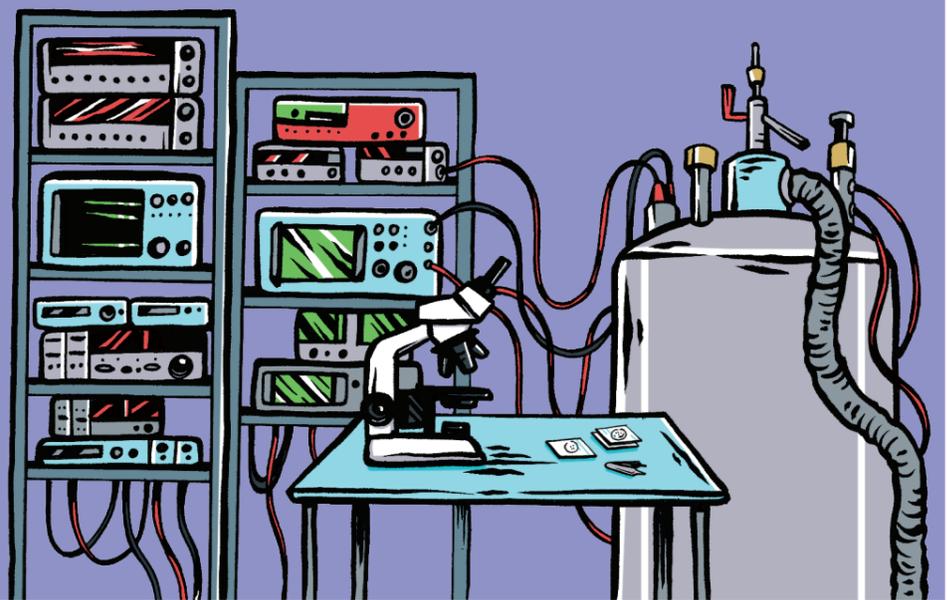


## THE QUESTION

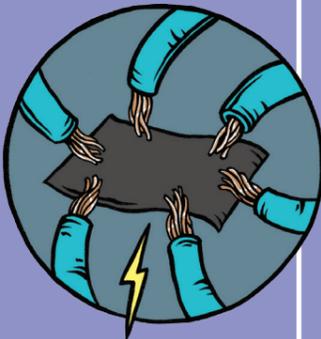
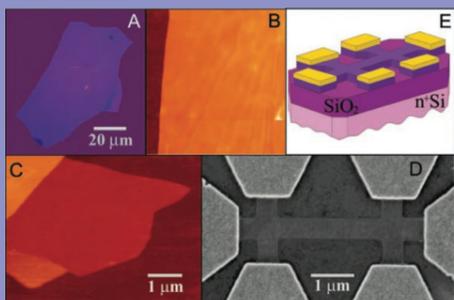


Could one create a material made of a single layer of carbon atoms from graphite? What would be its properties?

## THE LAB

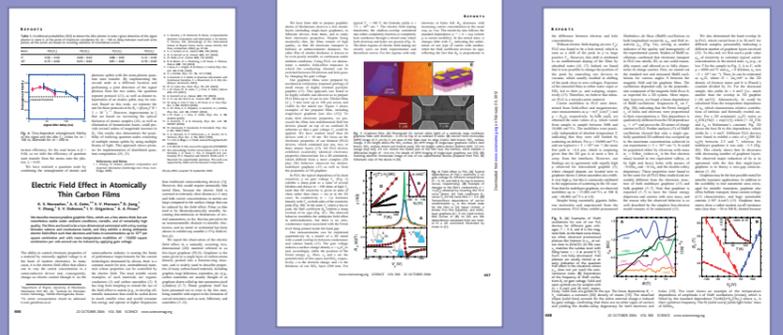


## THE RESULT



It is possible to create graphene, a 2 dimensional material of a single atom thick. Its mechanical properties are remarkable, and its electrical properties are surprising: neither an insulator nor a metal.

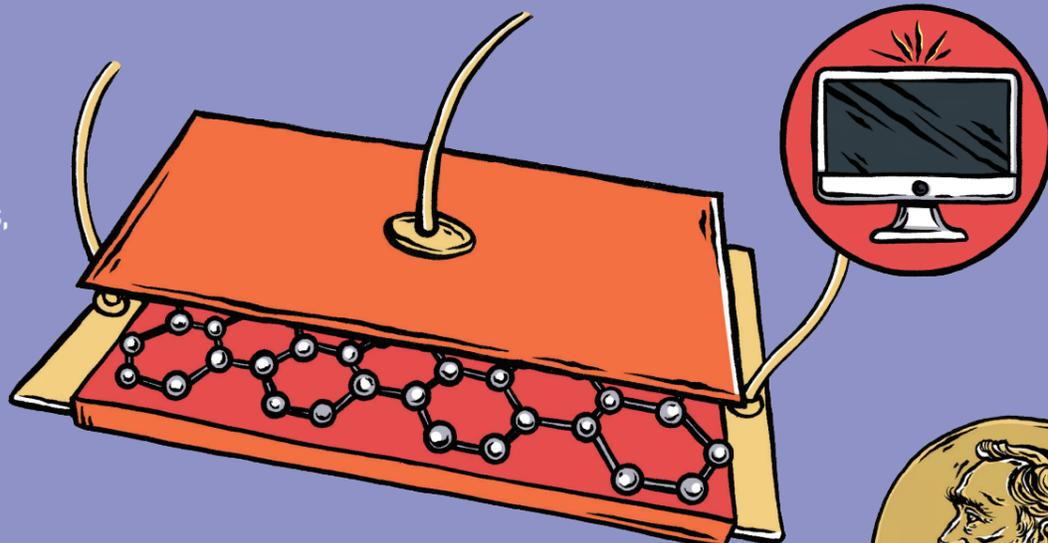
## THE ARTICLE



*Electric Field Effect in Atomically Thin Carbon Films,*  
K.S. Novoselov, et al., Science 306, 666 (2004)

## NOWADAYS

Graphene could have many applications, especially in nanophysics. Perhaps it will play a major role in electronics in the future.



**A. GEIM, K. NOVOSELOV, NOBEL PRIZE, 2010**  
For groundbreaking experiments regarding the two-dimensional material graphene.



# QUANTUM TALES TOPOLOGY, 1972 – 1985

D. THOULESS



M. KOSTERLITZ



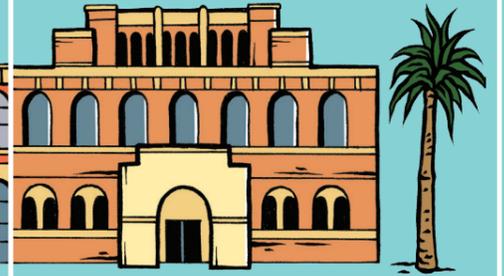
D. HALDANE



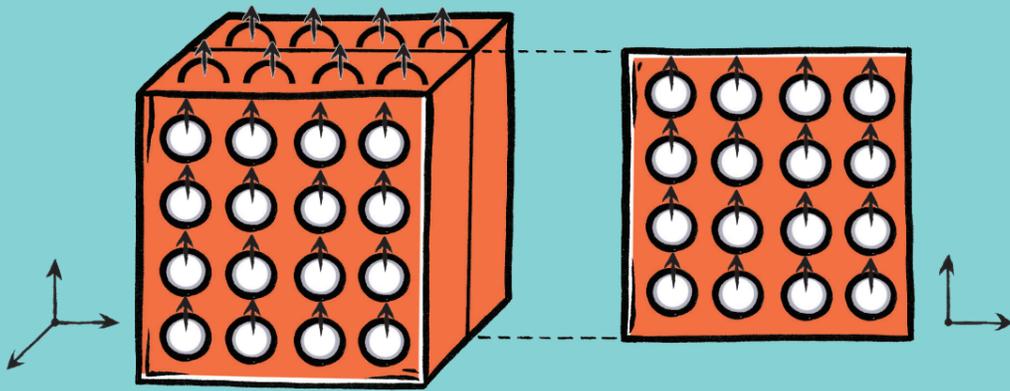
BIRMINGHAM UNIVERSITY,  
GREAT BRITAIN



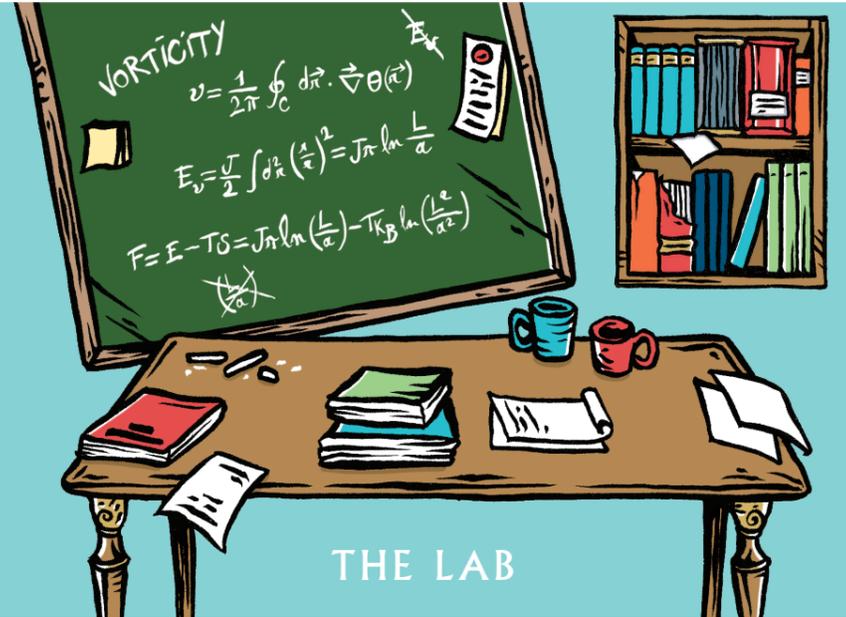
UNIVERSITY OF SOUTHERN  
CALIFORNIA, USA



## THE QUESTION



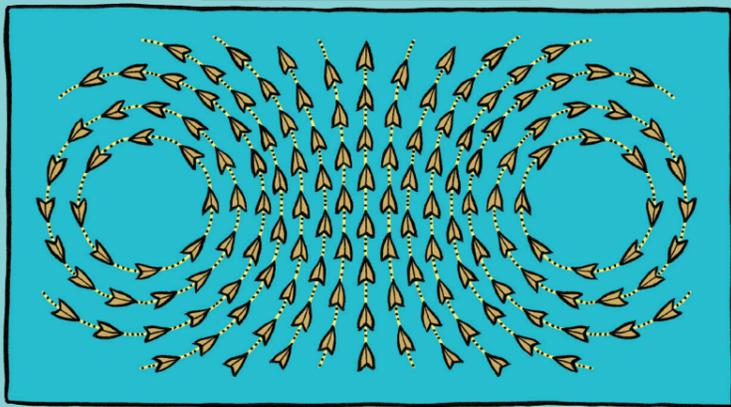
Can a superconductor or a magnet exist in two dimensions?



THE LAB

## THE RESULT

$$\frac{\pi J}{k_B T_c} - 1 \approx \pi \tilde{y}_c(0) \exp\left(\frac{-\pi^2 J}{k_B T_c}\right) \approx 0.12.$$



New states can appear in solids for topological reasons. For example in magnets or 2D superfluids, vortices and anti-vortices appear which allow the order to survive.

## THE ARTICLE

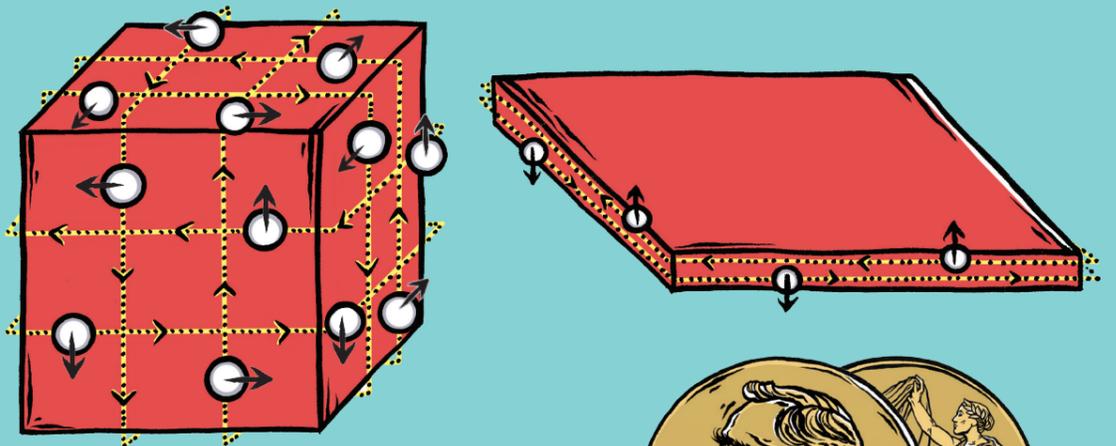


Ordering, metastability and phase transitions in two-dimensional systems  
J.M. Kosterlitz, D.J. Thouless,  
Journal of Physics C: Solid State Physics, 6, 1181 (1973).

## NOWADAYS



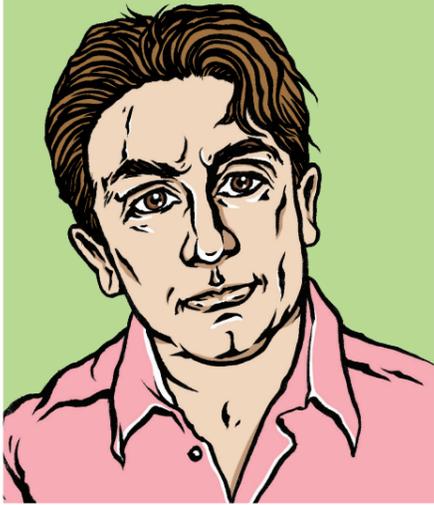
This work opened the route to the discovery of many new topological states in matter at one, two or three dimensions in magnets, metals or insulators.



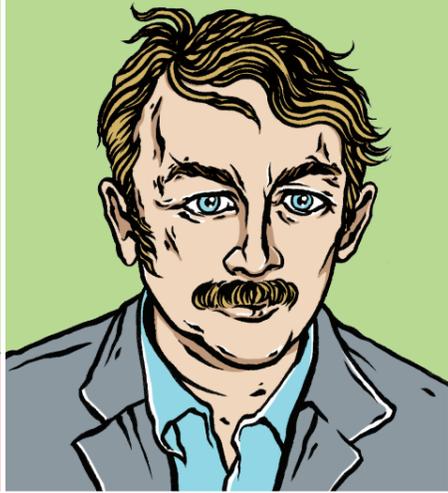
D. THOULESS, M. KOSTERLITZ, D. HALDANE, NOBEL PRIZE, 2016  
For theoretical discoveries of topological phase transitions and topological phases of matter.

# QUANTUM TALES GIANT MAGNETORESISTANCE, 1988

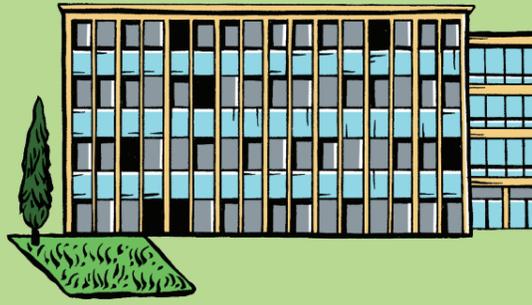
A. FERT



P. GRÜNBERG



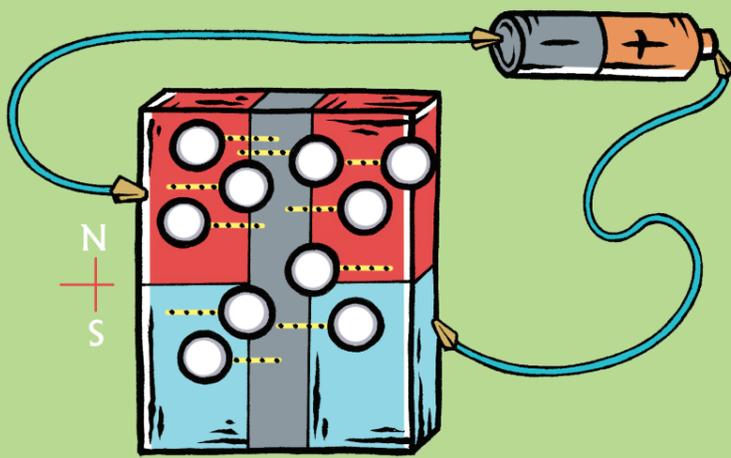
LABORATOIRE DE PHYSIQUE  
DES SOLIDES, ORSAY, FRANCE



JÜLICH INSTITUTE,  
GERMANY

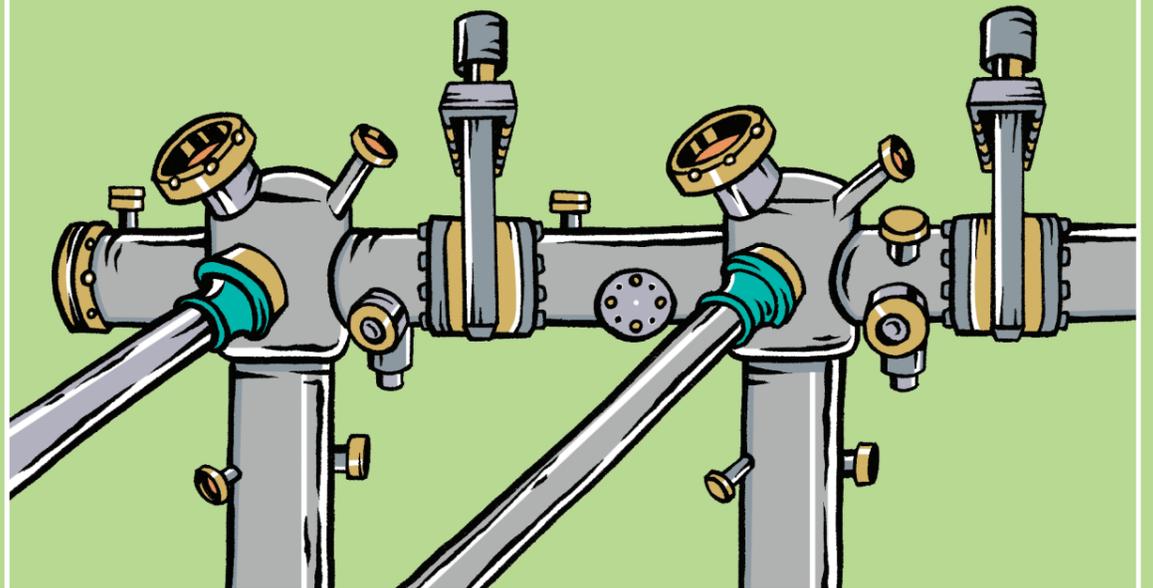


## THE QUESTION

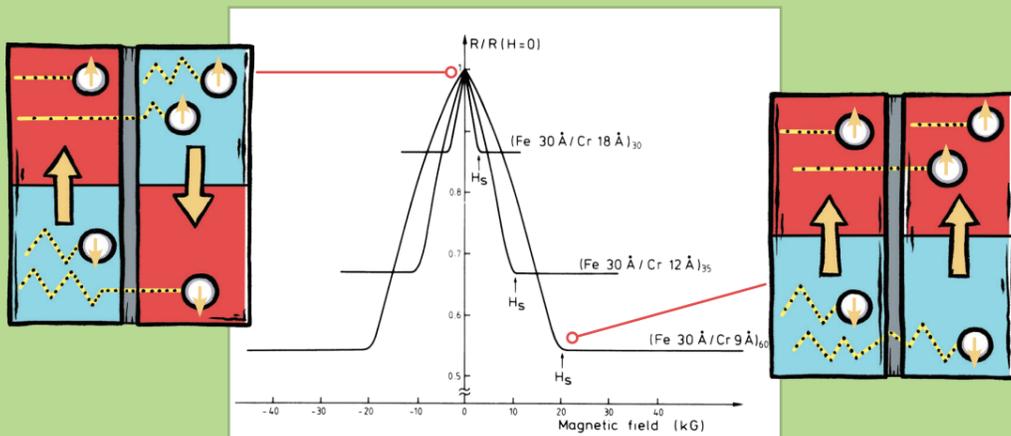


Is electrical current affected by the pole directions  
in thin magnetic layers?

## THE LAB

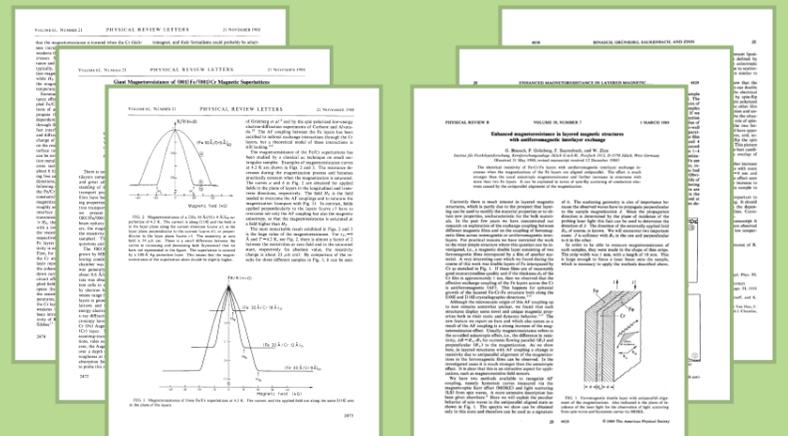


## THE RESULT



If one builds a magnetic “sandwich” and changes its poles, the electrical resistance changes a lot. In fact, the electrons carry a small magnet, the spin, which interacts with the magnetic sandwich.

## THE ARTICLES

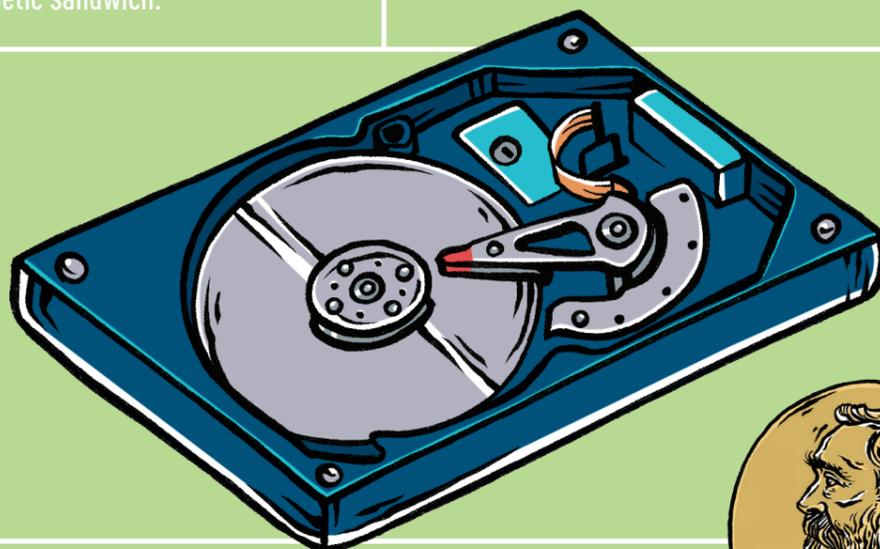


*Giant magnetoresistance  
of Cr magnetic superlattices,*  
M. N. Baibich et al., PRL 61, 2472 (1988)

*Enhanced magnetoresistance  
in layered magnetic structures,*  
G. Binasch et al., PRB 39, 4828 (1989)

## NOWADAYS

This discovery allowed the development  
of read-write head for hard disks.  
It has also opened a new field of research  
called spintronics.

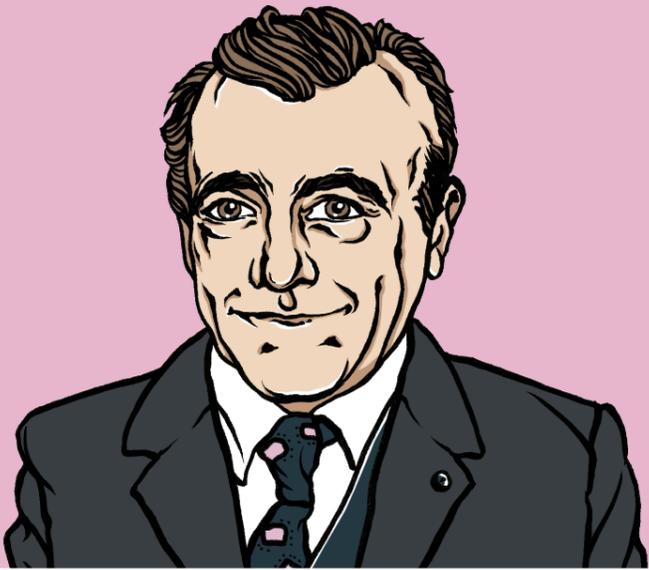


A. FERT, P. GRÜNBERG, NOBEL PRIZE, 2007  
For the discovery of giant magnetoresistance.

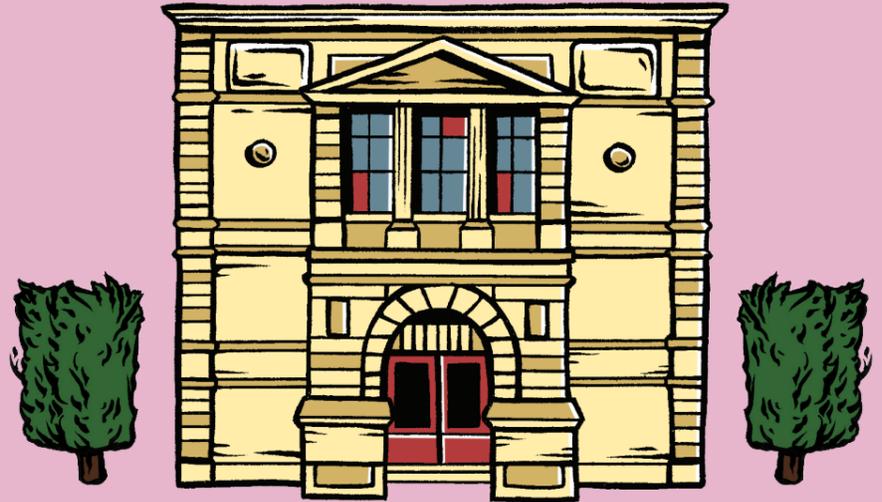


# QUANTUM TALES ANTIFERROMAGNETISM, 1936

L. NÉEL



INSTITUT DE PHYSIQUE DE STRASBOURG,  
FRANCE

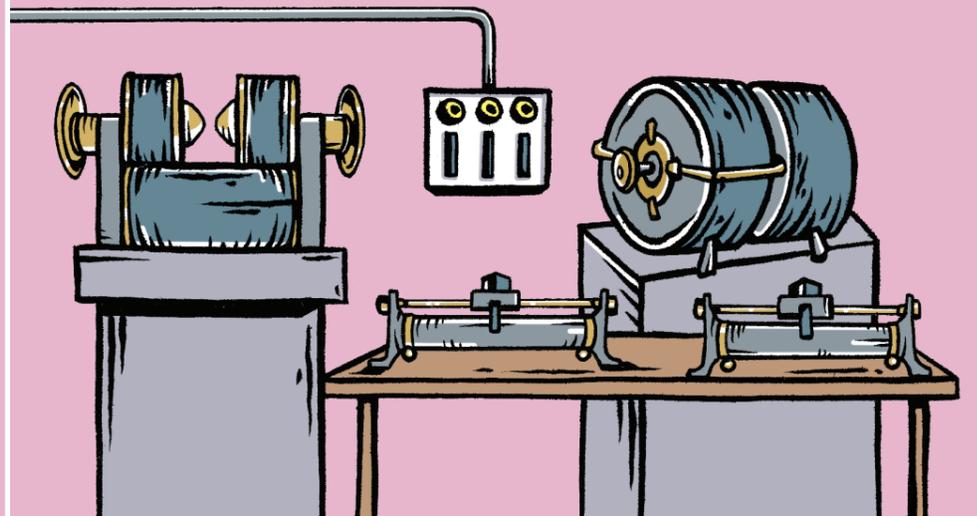


## THE QUESTION



Why some metals or oxides such as chromium do not seem to display any magnetism?

## THE LAB



## THE RESULT

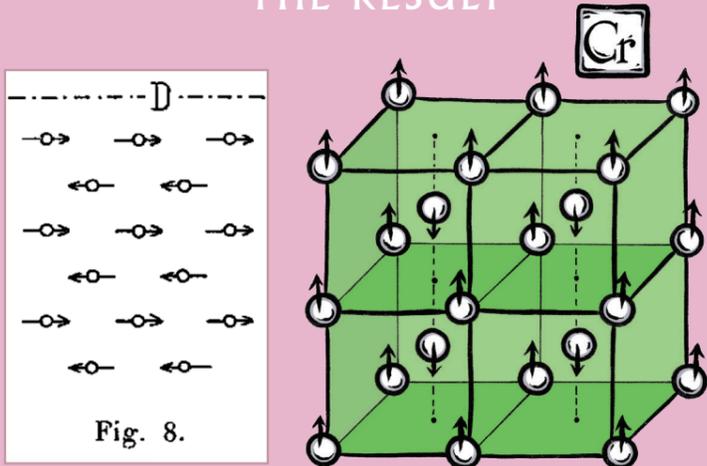
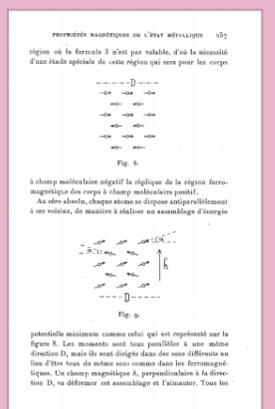


Fig. 8.

In some metals and oxides, the atoms carry small magnets called spins which order antiparallel to each other. These antiferromagnets do not show poles as in real magnets even though they too display a long range order.

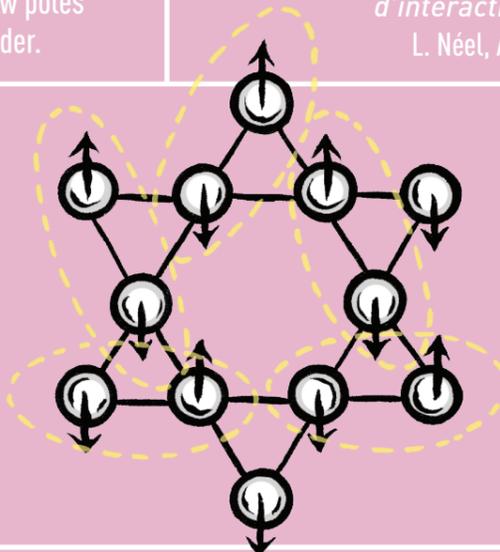
## THE ARTICLE



*Propriétés magnétiques de l'état métallique et énergie d'interaction entre atomes magnétiques,*  
L. Néel, Annales de Physique, 5, 232 (1936)

## NOWADAYS

The study of magnetism in solids is still a lively research field. For example, new "spin liquid" states have been recently discovered in solids which display star structures in which spins cannot order even close to absolute zero.



L. NÉEL, NOBEL PRIZE, 1970  
For the discovery of giant magnetoresistance.

# QUANTUM TALES SUPERCONDUCTIVITY, 1911

KAMERLINGH ONNES



LEYDEN UNIVERSITY, NETHERLANDS

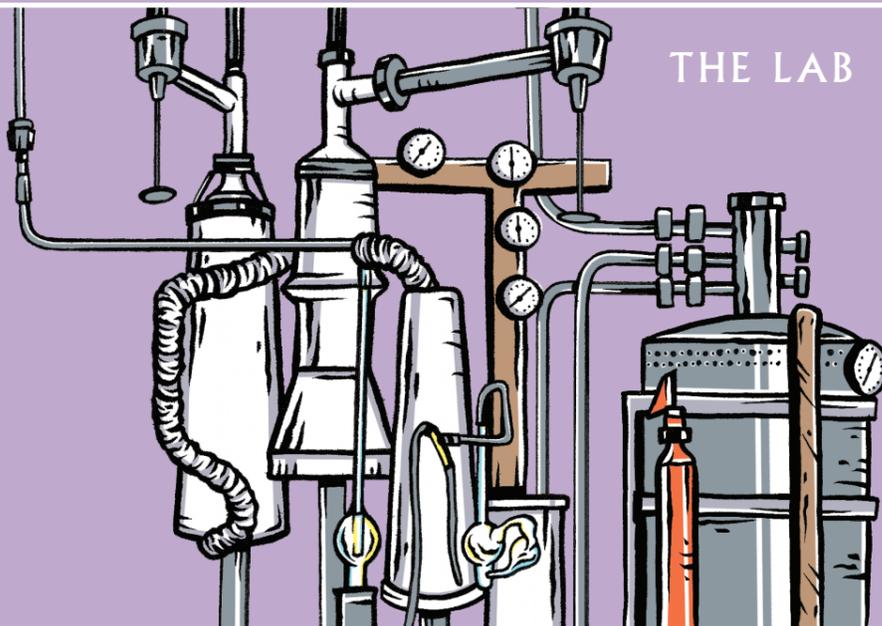


## THE QUESTION

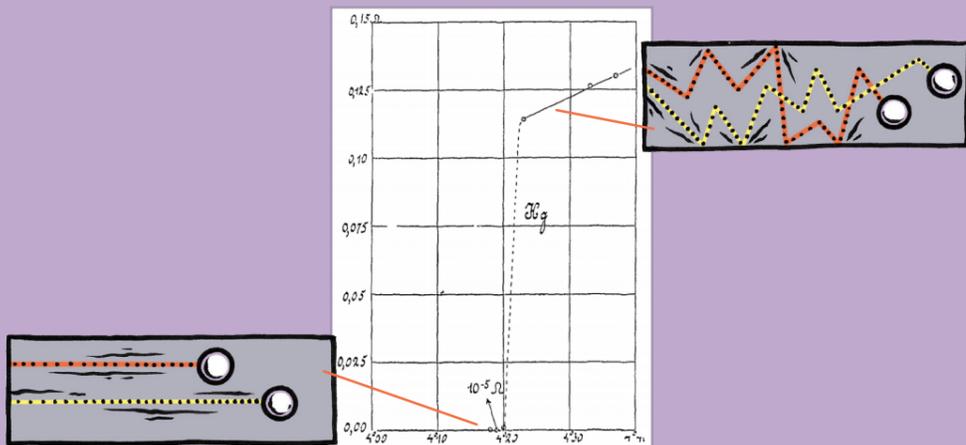


Does a metal such as mercury conduct better or worse at low temperature?

## THE LAB



## THE RESULT



The electrical resistance of mercury suddenly drops down to zero at low temperatures. The metal conducts perfectly: this is superconductivity.

## THE ARTICLE

...the theory of course which first of all takes account of the fundamental chemical facts which we mentioned above, but which further assumes: in treating the phenomena—particularly with respect to the specific heat—which adhere to the hypothesis on the chemical form indicated above at length in our previous paper. And thus it cannot be doubted, in our opinion, by what way we shall have to try to find such a theory. We shall have to extend the theory of indissoluble units of energy, which has led to such remarkable results, to the chemical phenomena; it will be necessary to investigate in what way the properties of the reversible chemical reactions are concerned with the phenomena of radiation. Was this connection, but have found, the course is indicated to calculate the difference of energy of a chemical reaction by the aid of the statistical theory of energy at temperatures at which the reaction can actually take place, and then it will be very simple to calculate by the aid of the acquired knowledge of the specific heat the difference of energy also for temperatures, at which there can no longer be question of chemical reactions.

One of us has been occupied with this question, and hopes to be able before very long to publish further communications on this subject.

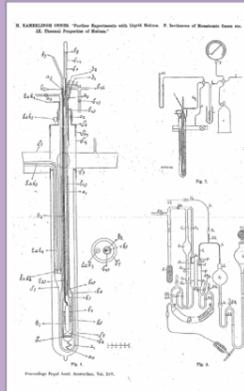
Physics. — "Further Experiments with Liquid Helium. G. On the Electrical Resistance of Pure Metals, etc. VI. On the Sudden Change in the State at which the Resistance of Mercury Disappears." By H. KAMERLINGH ONNES. Communication N° 124c from the Physical Laboratory at Leyden. — *Communications to the Society of November 28, 1911.*

1. Introduction. In Comm. N° 123b (Proc. May 1911) I mentioned that just before this resistance disappeared practically altogether, its rate of diminution with falling temperature became much greater than that given by the formula of Comm. N° 123. In the present paper a closer investigation is made of this phenomenon.

1.1. Development of the resistance. A description was given in Comm. N° 123 (Proc. June 1911) of the crystal which, by allowing the contained liquid to be stirred, enabled me to keep constant at uniform well-defined temperatures and in the paper I mentioned that measurements of the resistance of mercury at the lowest possible temperatures had been repeated using a mercury resistance with mercury leads. The immersion of a resistance with such leads in a bath of liquid helium was rendered possible only by the successful construction of the crystal.

The accompanying Plan, which should be compared with the Plan of Comm. N° 123, shows the mercury resistance with a portion of the leads in its position diagrammatically in fig. 1. Some glass tubes of about 0.005 m. diam. were cemented and joined together at their upper ends by inverted Y-pieces which are shown at above, and are not quite filled with mercury; this gives the mercury an opportunity to contract or expand on freezing or liquefying without breaking the glass and without breaking the continuity of the mercury thread formed in the seven tubes. To the Y-pieces A and A', are attached two leading tubes H<sub>1</sub>, H<sub>2</sub>, and H<sub>3</sub>, H<sub>4</sub>, whose lower portions are shown at H<sub>1</sub>, H<sub>2</sub>, H<sub>3</sub>, H<sub>4</sub>, filled with mercury which, on solidification, forms four leads of solid mercury. To the connector A, is attached a single tube H<sub>5</sub>, whose lower part is shown at H<sub>5</sub>. At A, and A', contact tubes and leads through the tubes H<sub>1</sub>, H<sub>2</sub>, and H<sub>3</sub>, and H<sub>4</sub>, can be used for the same purpose or also for determining the potential difference between the ends of the mercury thread. The mercury filled tube H<sub>5</sub> can be used for measuring the potential at the point A. To take up any gaps in the crystal and to find room throughout the stirring point B, the tubes which are shown in one place in fig. 1 were closed together in the manner shown in fig. 2. The position in the crystal is to be seen from fig. 4 where the other parts are indicated by the same letters as were used in the Plan of Comm. N° 123. The leads project above the cover D, in a manner shown in perspective in fig. 3. They too are provided with expansion spaces, which in the last case possess air filled platinum wire H<sub>1</sub>, H<sub>2</sub>, H<sub>3</sub>, H<sub>4</sub>, H<sub>5</sub>, which are connected to the measuring apparatus. The apparatus was filled with mercury distilled ever so many times at a temperature of 60° to 70° C. while the cold portion of the distilling apparatus was immersed in liquid air.

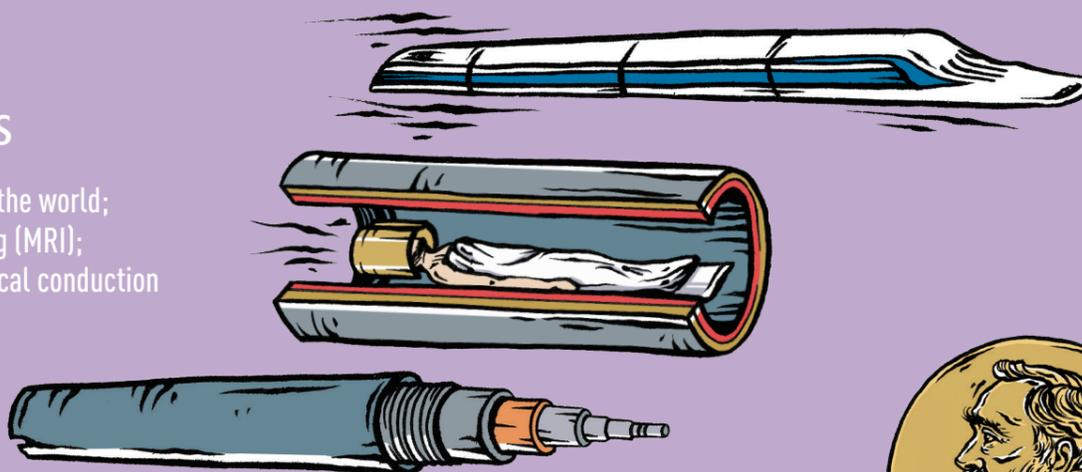
1.2. Results of the Measurements. The positions of the platinum wires with the copper leads of the measuring apparatus were protected as effectively as possible from temperature variation. The mercury resistance itself with the mercury leads, which served for the measurement of the fall of potential across, however, on immersion in liquid helium to be the end of a considerable super-conductor from the sign of the same tubes to fill it with perfectly pure mercury. The magnitude of the thermoelectric effect did not change much when the resistance was immersed in liquid hydrogen or in liquid air instead of in liquid helium, and we may therefore conclude that it is intimately connected with phenomena which occur in the neighborhood of the transition point.



Further experiments with Liquid Helium  
Com. N°124c from the Phys. Lab. at Leyden, 1911

## NOWADAYS

levitating train: the fastest in the world;  
magnetic resonance imaging (MRI);  
electrical cables: for better electrical conduction



## K. ONNES, NOBEL PRIZE, 1913

For his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium.

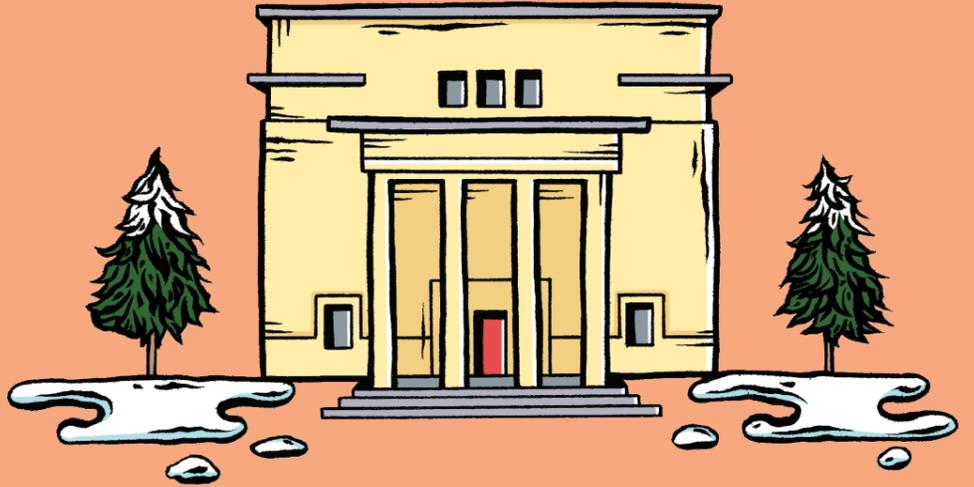


# QUANTUM TALES SUPERFLUIDITY, 1937

P. KAPITSA



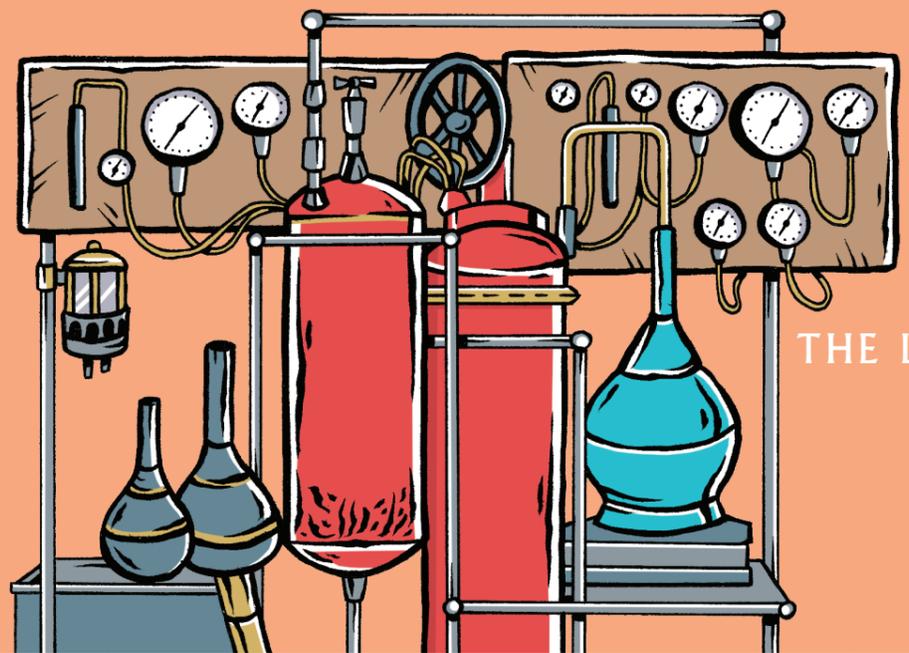
INSTITUTE FOR PHYSICAL PROBLEMS,  
MOSCOW, RUSSIA



## THE QUESTION

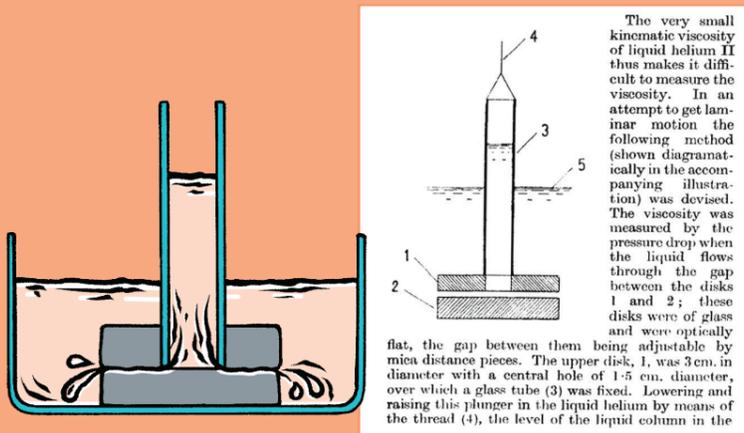


What does a liquid become at close to absolute zero if it doesn't freeze?



THE LAB

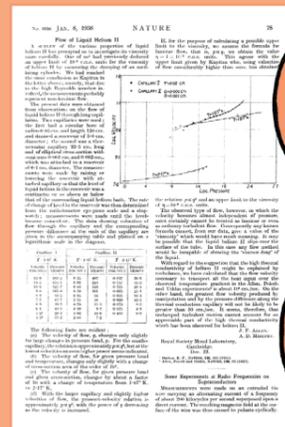
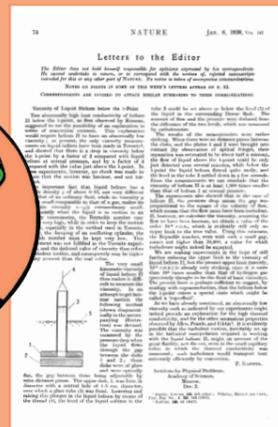
## THE RESULT



The very small kinematic viscosity of liquid helium II thus makes it difficult to measure the viscosity. In an attempt to get laminar motion the following method (shown diagrammatically in the accompanying illustration) was devised. The viscosity was measured by the pressure drop when the liquid flows through the gap between the disks 1 and 2; these disks were of glass and were optically flat, the gap between them being adjustable by mica distance pieces. The upper disk, 1, was 3cm. in diameter with a central hole of 1.5 cm. diameter, over which a glass tube (3) was fixed. Lowering and raising this plunger in the liquid helium by means of the thread (4), the level of the liquid column in the

Liquid helium close to absolute zero is placed in a column above two disks. The helium then flows out between the disks even when the disks touch each other. Kapitza calls it superfluidity.

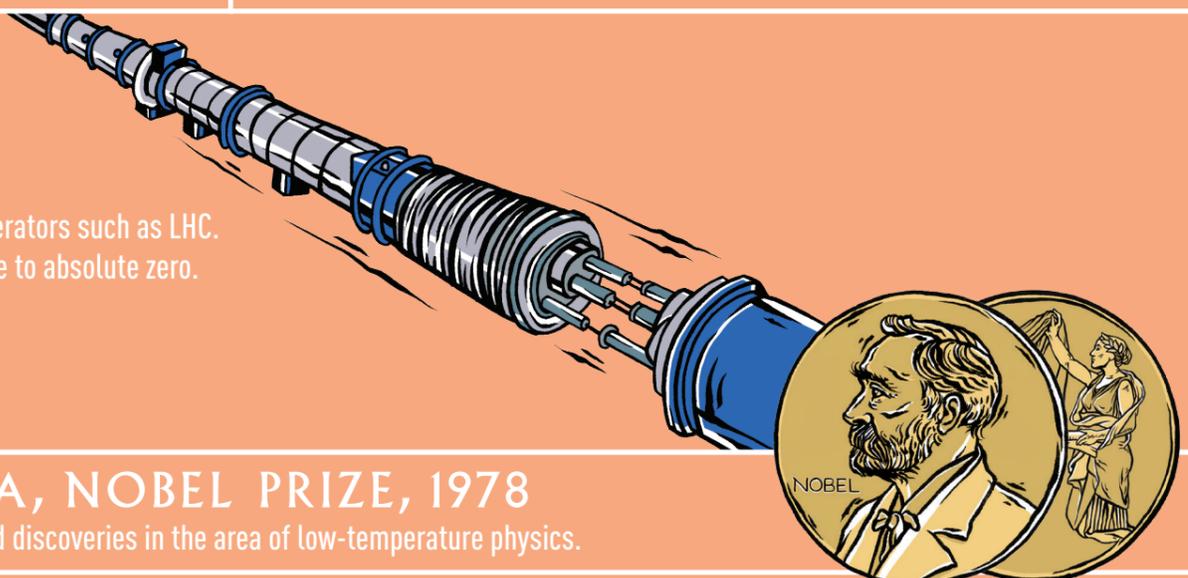
## THE ARTICLES



*Viscosity of Liquid Helium below the  $\lambda$ -Point*, P. Kapitza, Nature 74, 141 (1938)  
*Flow of liquid helium II*, J.F. Allen, A.D. Misener, Nature 75, 141 (1938)

## NOWADAYS

Superfluid helium allows cooling down particle accelerators such as LHC. It is also an essential tool for physics research close to absolute zero.



P. KAPITSA, NOBEL PRIZE, 1978

For his basic inventions and discoveries in the area of low-temperature physics.