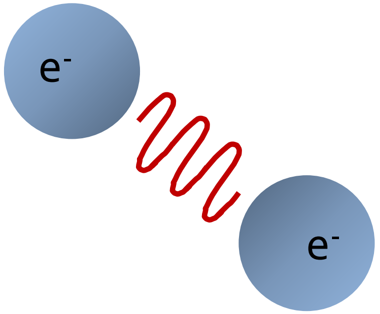
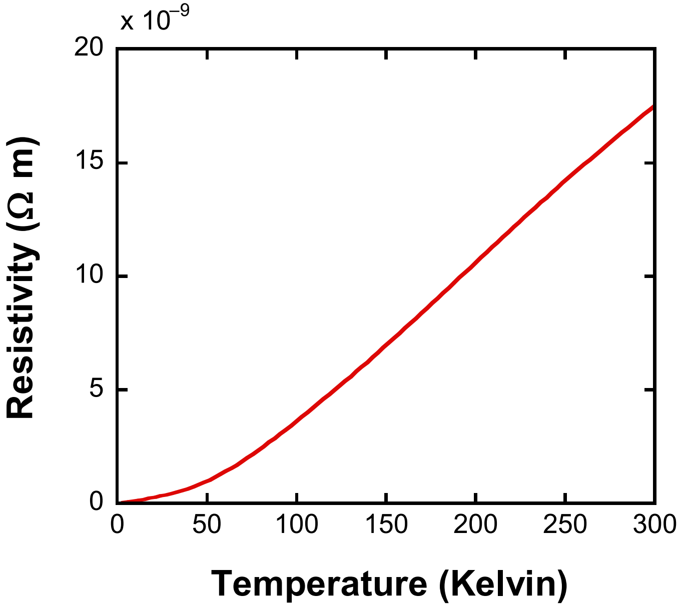
Superconductivity
Lecture 1

Alexy Karenowska
Department of Physics, University of Oxford

- **What is ‘super’ about superconductivity?**
- **What is electrical resistivity?**
- **The discovery of superconductivity**
- **Superconductors in magnetic fields**
- **Introducing electron pairing**



Slides adapted with enormous gratitude from those of Prof. Andrew Boothroyd



Resistivity of copper

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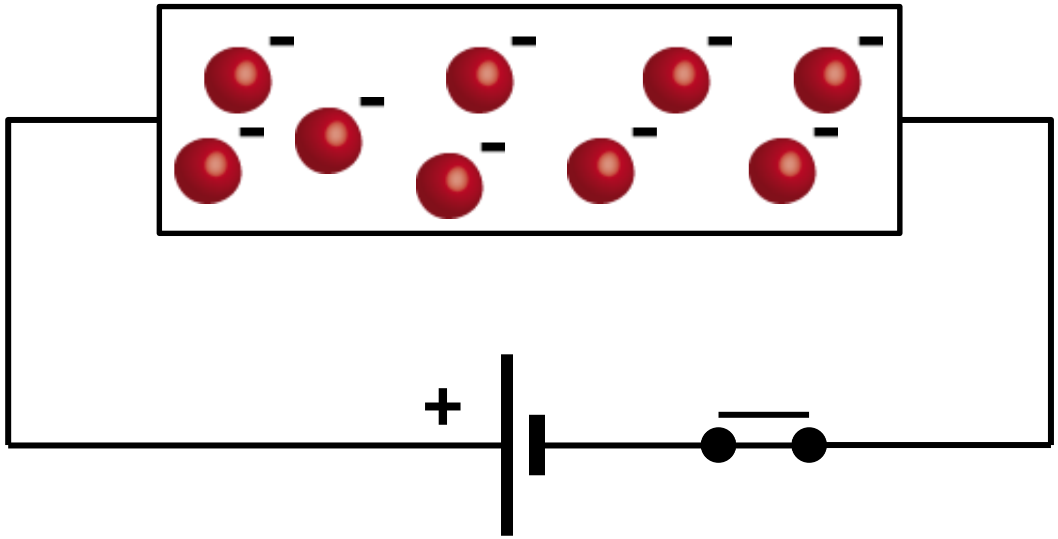
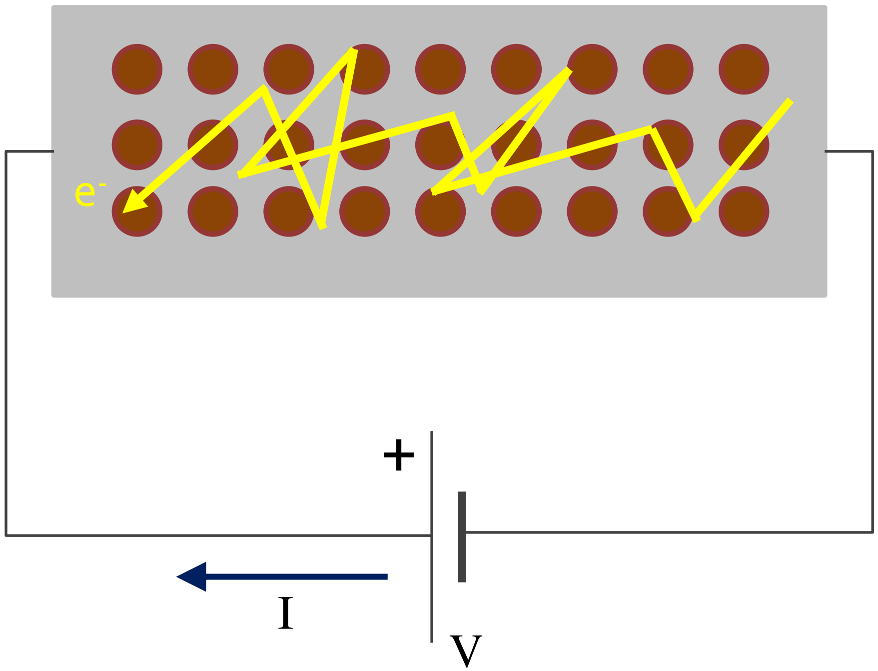




Ohm's Law: $V = IR$

$R = \rho L/A$

ρ = resistivity
$\sigma = \rho^{-1}$ = conductivity

$\rho_{copper} = 17 \times 10^{-9}\ \Omega m$
$\rho_{seawater} = 0.2\ \Omega m$
$\rho_{teflon} > 10^{22}\ \Omega m$

Instantaneous velocity $v = \sim 10^5$ to 10^6 m s^{-1}

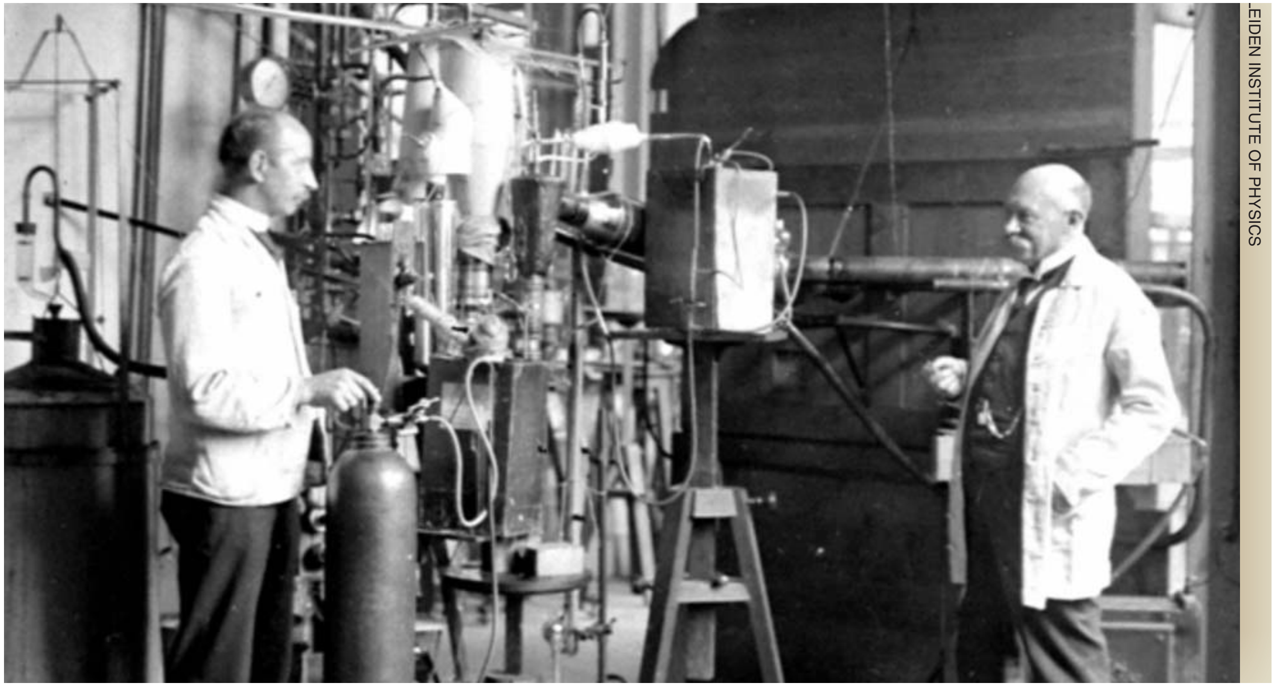
Drift velocity $v_\mathrm{D} \propto I$

$$\Delta Q = enAv_\mathrm{D}\Delta t$$

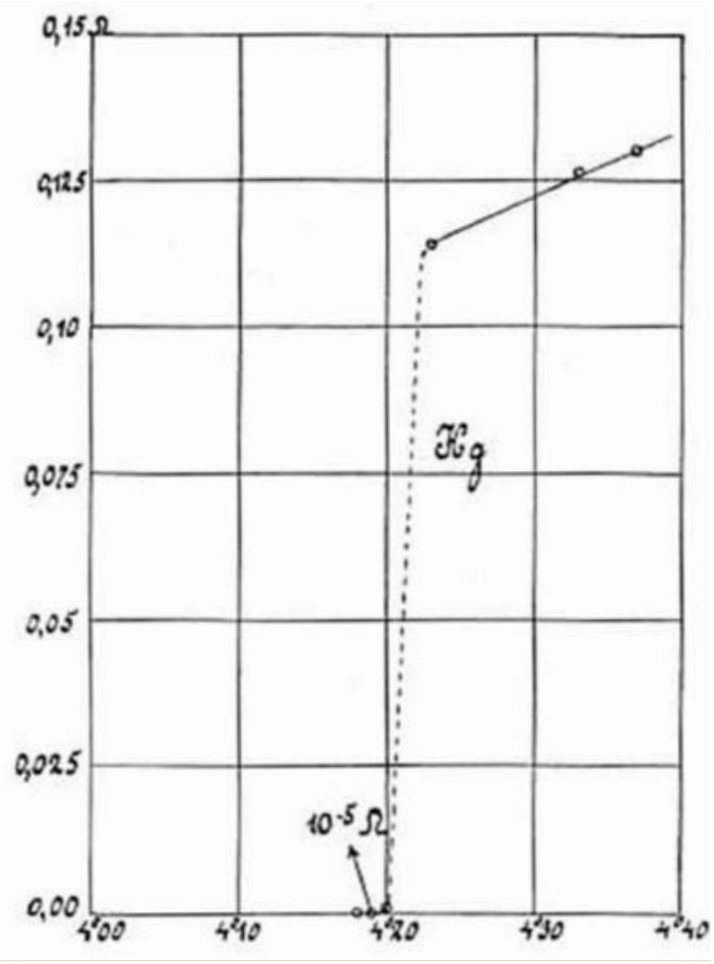
r = 1mm
I = 0.5A
$n = 10^{28}$ m^{-3}

$$j = \frac{I}{\pi r^2}$$

"Kwik nagenoeg nul"



Heike Kamerlingh Onnes and Gerrit Film, Leiden c. 1911



Superconducting transition in mercury (2.2K) is measured for the first time. April 1911, data above taken October of same year.

The Nobel Prize in Physics 1913 was awarded to Heike Kamerlingh Onnes "for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium."

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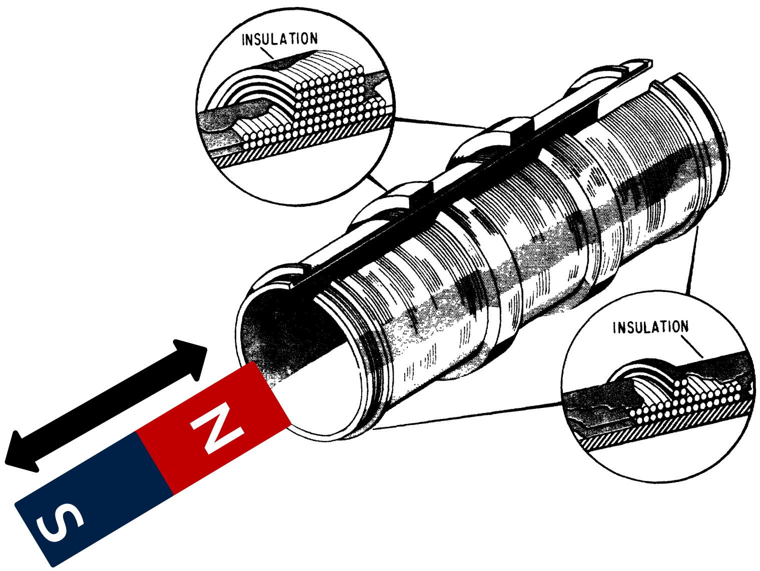
OBSERVATION OF PERSISTENT CURRENT IN A SUPERCONDUCTING SOLENOID

J. File and R. G. Mills
Plasma Physics Laboratory, Princeton University, Princeton, New Jersey
(Received 21 September 1962; revised manuscript received 26 December 1962)



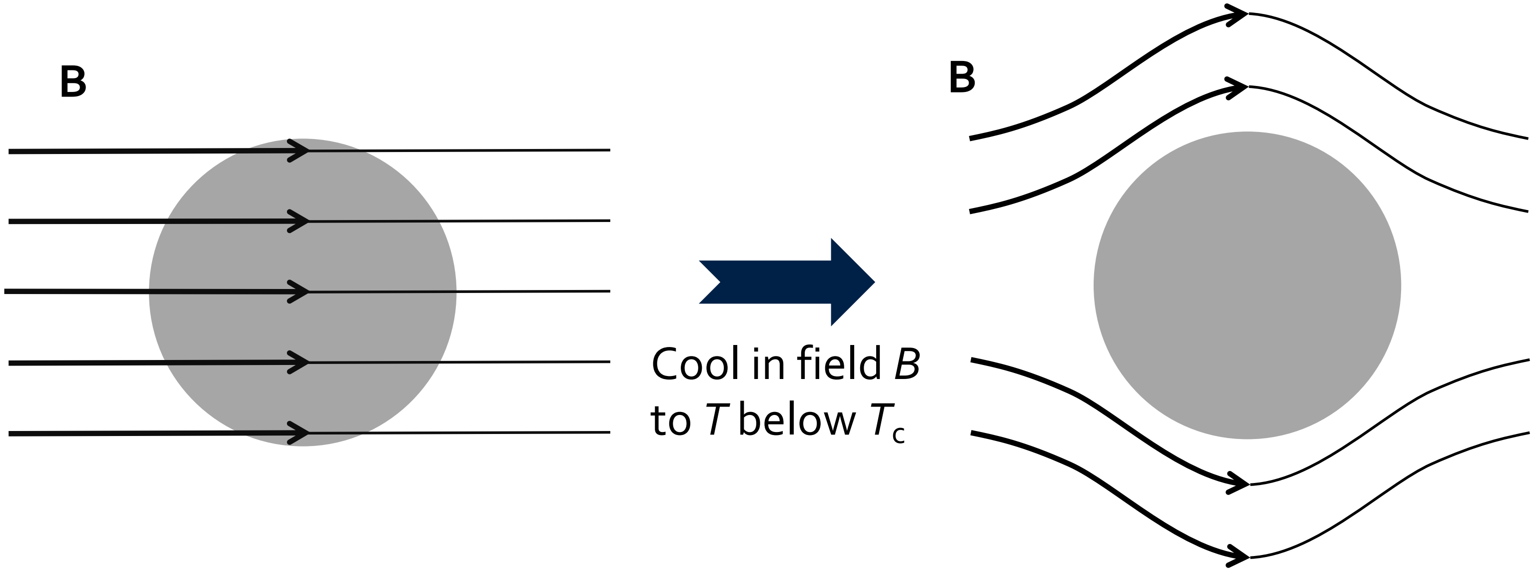
Current persists for $>10^5$ years

Resistivity $<10^{-23}\,\Omega m$
(15 orders of magnitude smaller than Copper)

Walter Meissner
(1882-1974)

Robert Ochsenfeld
(1901-1993)

The Meissner-Ochsenfeld effect, 1933



Karl Alexander Müller, b. 1927

Georg Bednorz, b. 1950

Discovery of copper oxide superconductors, 1986
Nobel prize, 1987

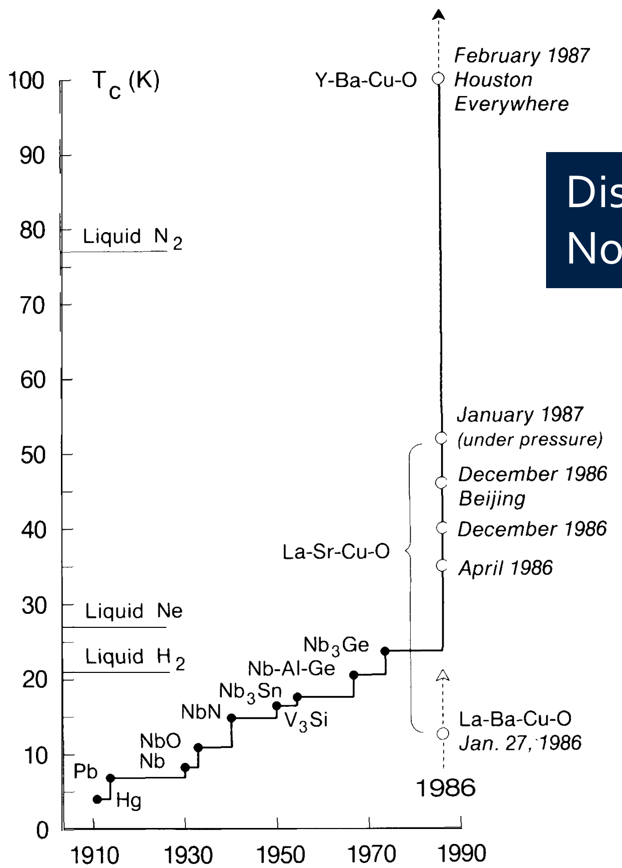
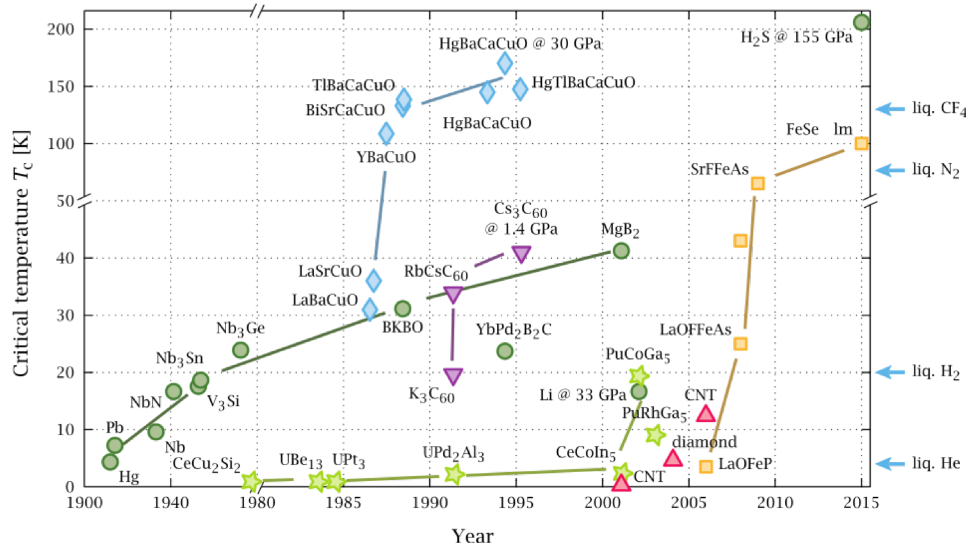


Figure 1.13. Evolution of the superconductive transition temperature subsequent to the discovery of the phenomenon. From [1.29], © 1987 by the American Association for the Advancement of Science.

Lowest temperature recorded on earth is -89.2 °C, 184 K



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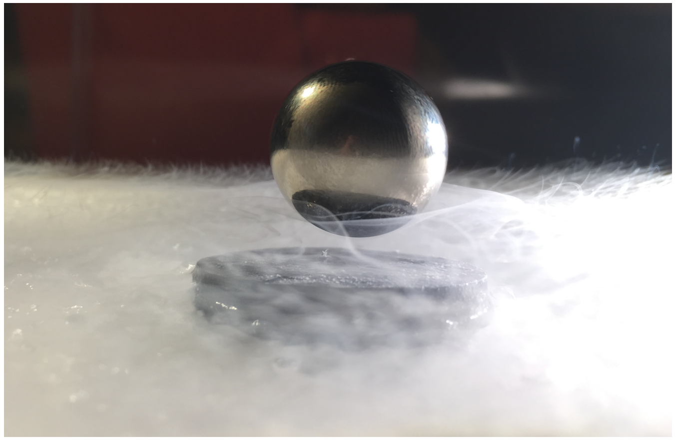
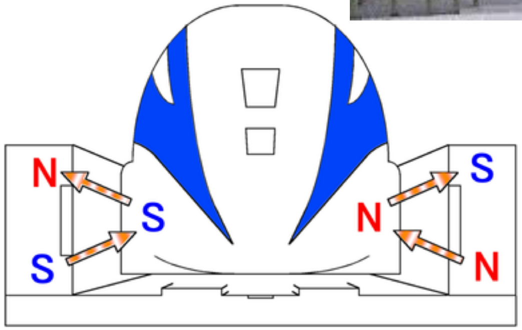


Maglev trains (EDS — electrodynamic suspension)

- Onboard high T_c magnets combined with magnets in rails
- Speeds in excess of 350 mph



London penetration depth. In 1935, F. and H. London, who were working in Oxford at the time, showed that a magnetic field applied parallel to the surface of a superconductor would penetrate a short distance into the superconductor. They derived the following equation for the variation of field $B(z)$ with distance z into the superconductor:

$$\frac{d^2B(z)}{dz^2} = \frac{B(z)}{\lambda^2},$$

where

$$\lambda^2 = \frac{m_e}{\mu_0 n e^2}.$$

Here, $m_e = 9.11 \times 10^{-31}$ kg is the mass of the electron, $\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1} is the permeability of free space, $e = 1.60 \times 10^{-19}$ C is the electronic charge, and n is the number of electrons per unit volume.

If the field at the surface ($z = 0$) is B_0, show that the field decays exponentially into the superconductor. Make an estimate of λ and calculate the depth at which the field has decayed to $B_0/10$.
[Hint: If you do not know how to solve the first equation above directly, try substituting

$$B(z) = Cexp(-z/\lambda) + Dexp(z/\lambda)$$

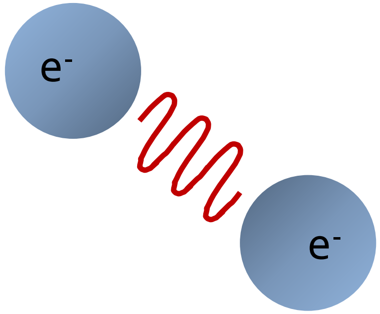
and use the value of $B(z)$ at $z = 0$ and $z = \inf$ to determine the constants C and D.]

Superconducting wire. A wire is to be made from the superconductor Nb_3Sn, which has a critical magnetic field $B_c = 20$ Tesla. What is the minimum radius of the wire if it is to carry a current of 10^4 Amps?

What would happen if the current exceeded this value? What could be done to prevent damage to the wire?

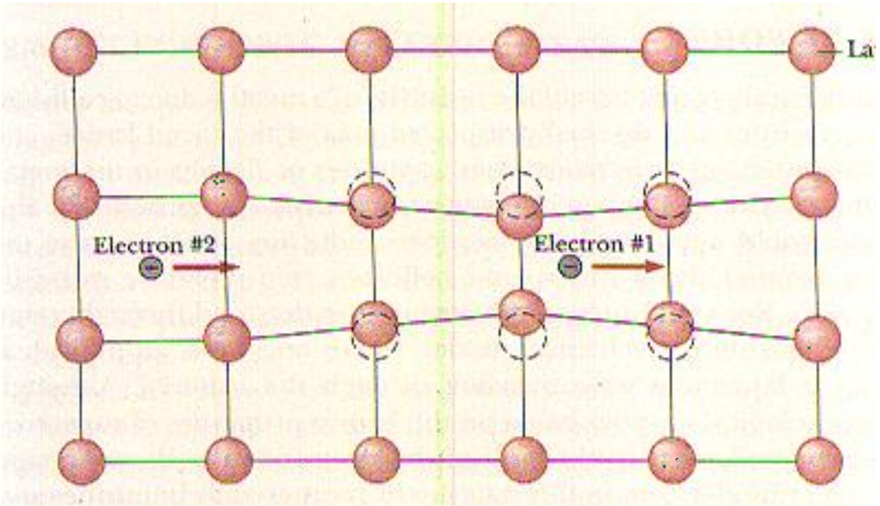
[Hint: for the first part: The magnetic field outside a wire carrying a current I is given by $B(r) = \mu_0 I/(2\pi r)$, where r is the distance from the centre of the wire.]

Next lecture



Superconducting electrons are bound in a **condensate** of **pairs**

What is the pairing mechanism?



Electrons cause instantaneous distortion of ionic lattice and leave "trail" of positive charge.