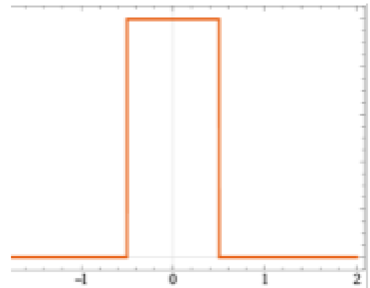
DSE CLASS

CONDENSED MATTER PHYSICS

Lecture-2

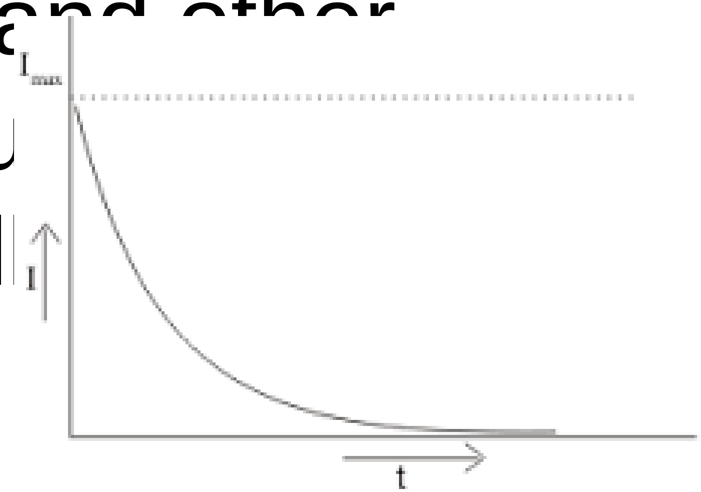
10/09/2020

What happens if we apply a voltage puls



The current that starts to flow will eventually disappear.

This is because electrons scatter inelastically from phonons a electrons as they flow throu metals, eventually losing al energy.



Persistent Currents

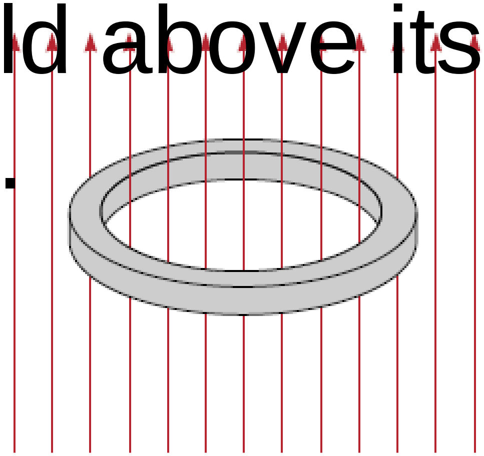
The dc resistance of a superconductor is zero below the critical temperature, once a current is set up in the material, it persists without any applied voltage.

These persistent currents, sometimes called supercurrents, have been observed to last for several years with no measurable losses.
In one experiment conducted by **S. S. Collins** in Great Britain, a current was

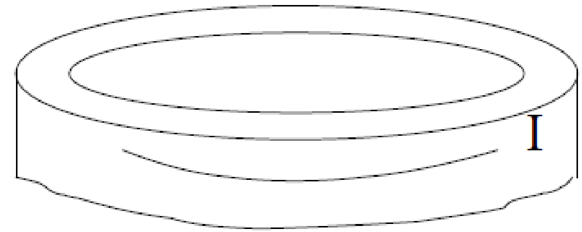
Sensitive method for detecting small resistance– look for decay in current around a closed loop of superconductor.

It uses the magnetic moment of a persistent current I_p in a ring to determine the decay rate of I_p rather than the resistance itself.

Let us consider a ring made of a superconductor is placed in a magnetic field above its critical temperature.



It is then cooled below Tc.



If the magnetic field is removed, a current
is induced in ring due to its self-inductance.

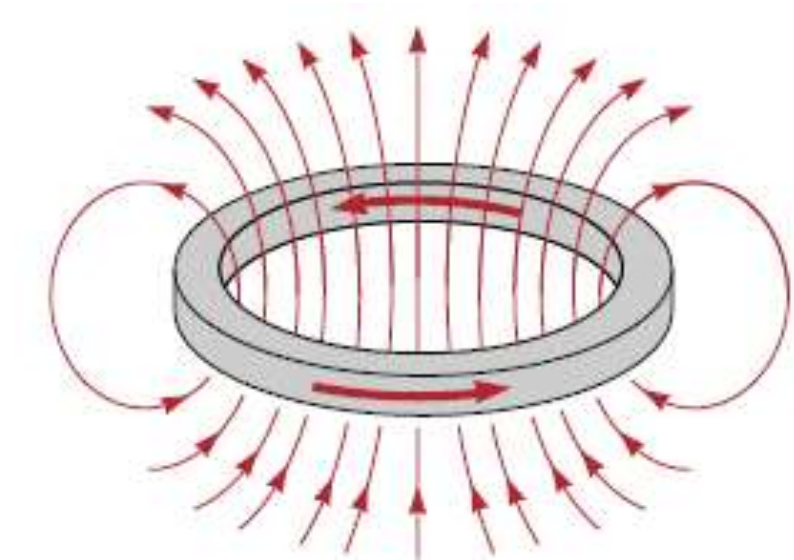
By Lenz law the direction of this induced current is such that it opposes the change in flux passing through the ring.

As the ring is in superconducting state,

If loop has resistance R and self-inductance L, current
should decay with time constant t
where ***t = L/R***
Failure to observe decay
upper limit of 10^{-26} Ωm for resistivity in superconducting state

This persistent current produce a magnetic flux which makes the magnetic flux passing through the ring constant.

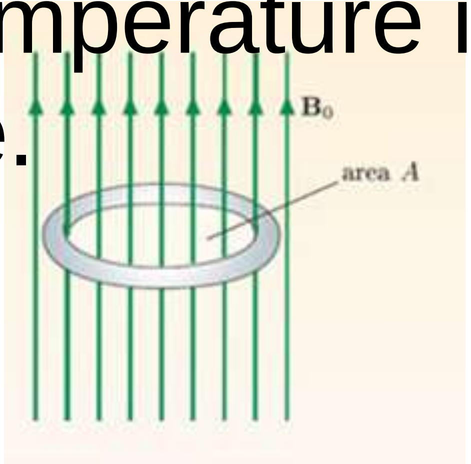
The superconducting ring prevents the flux from going to zero through a large spontaneous current induced by the collapsing external magnetic field.



If the dc resistance of the superconducting wire is truly

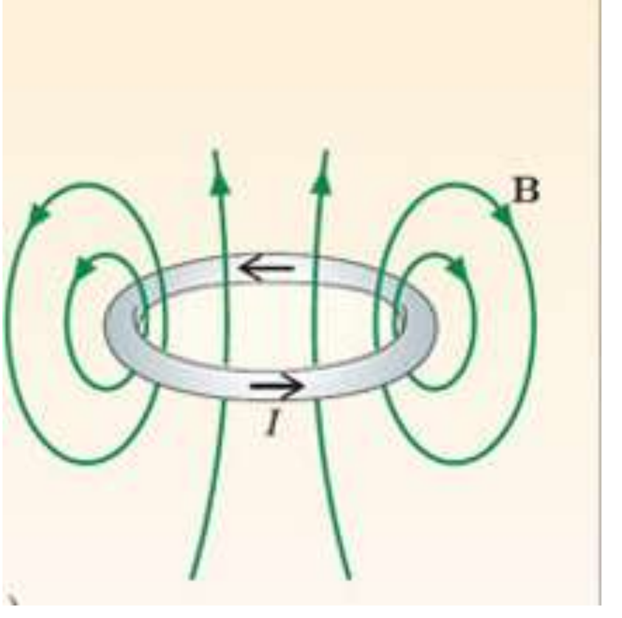
An important consequence of the persistent currents that flow in materials with zero resistance is that the magnetic flux that passes through a continuous loop of such a material remains constant.

To see how this comes about, consider a ring of metal, enclosing a fixed area A. An initial magnetic field Bo is applied perpendicular to the plane of the ring when the temperature is above the critical temperature.



The magnetic flux Φ through the ring is B_oA, and if the ring is cooled below its critical temperature while in this applied field, then the flux passing through it is unchanged.

If we now change the applied field, then a current will be induced in the ring, the direction of this current will be such that the magnetic flux it generates compensates for the flux change due to



From Faraday's law, the induced emf in the ring is

$$e = d\phi/dt = -A\,d(B-B_o)/dt$$

and this generates an induced current I given by

$$-A\,dB/dt = RI + L\,dI/dt$$

where L is the self-inductance of the ring. Note that there is no ohmic term, IR, on the left-hand side of this equation, because we are assuming that IR = 0.

Integrating this equation, we obtain

$$LI + BA = \text{constant}.$$

But ***LI*** is the amount of flux passing through the ring generated by the current ***I*** flowing in the ring.

So ***(LI + BA)*** is the total magnetic flux through the ring.

If the applied magnetic field is changed, an induced current is set up that creates a flux to compensate exactly for the change in the flux from the applied magnetic field.

$$LI + BA = LI' + B'A$$

Because the circuit has no resistance, the induced current can flow indefinitely, and the original amount of flux through the ring can be

The current is rather a result of maintaining the flux fixed.

This is true even if the external field is removed altogether;
the flux through the ring is maintained by a persistent induced current I_p,

$$LI + BA = LI' + BA' = LI_p$$

The second defining characteristic of a superconducting material is much less obvious than its zero electrical resistance.

Diamagnetism

- A superconductor is not only a perfect conductor (R=0), but a perfect diamagnet.
- It will tend to repel a magnet.

It was over 20 years after the discovery of superconductivity that **Meissner** and **Ochsenfeld** published a paper describir ristic.

Walter Meissner

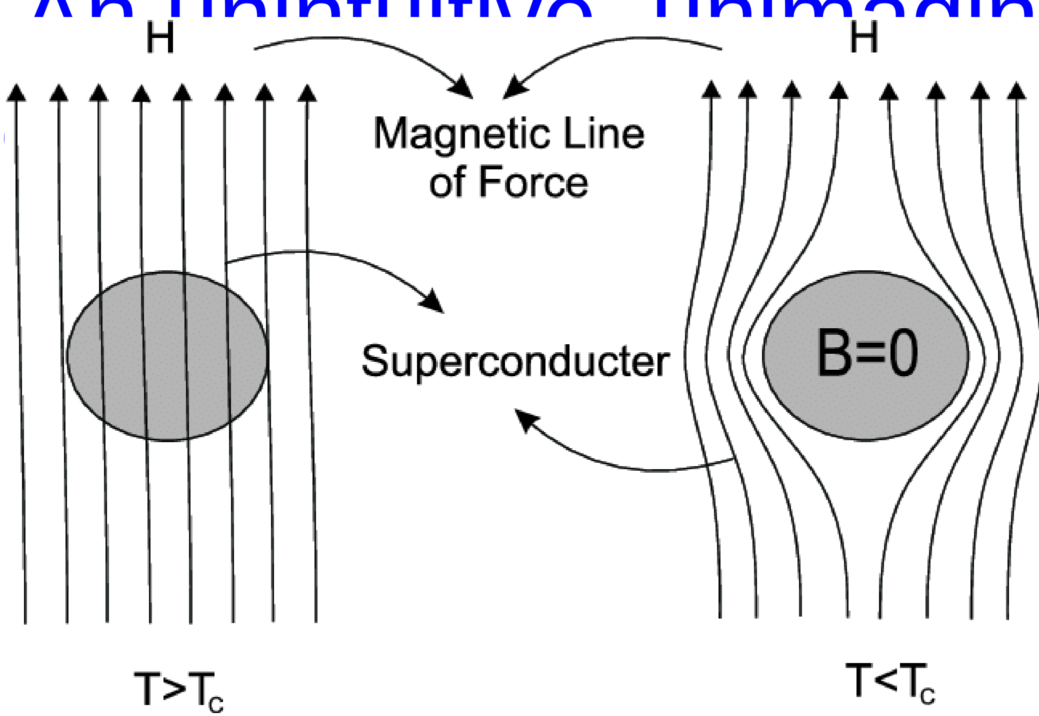
Robert Ochsenfeld

They discovered that when a magnetic field is applied to a sample of tin, in the superconducting state, the applied field

Perfect diamagnetism Meissner effect

- The next hall mark to be discovered was the perfect diamagnetism, in 1933 by Meissner and Oschenfield

- An unintuitive, unimaginable property

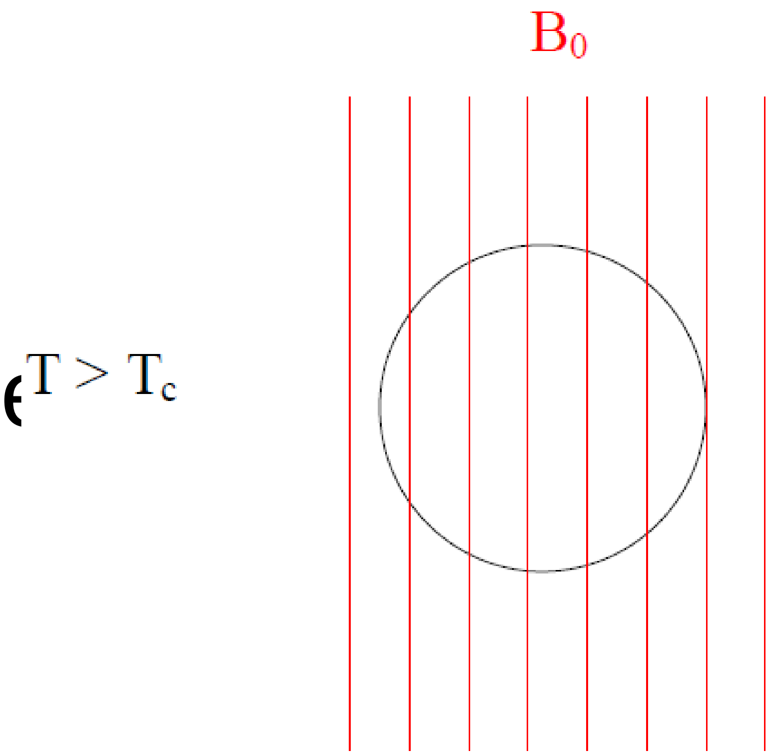


What happens to magnetic field inside superconductor?

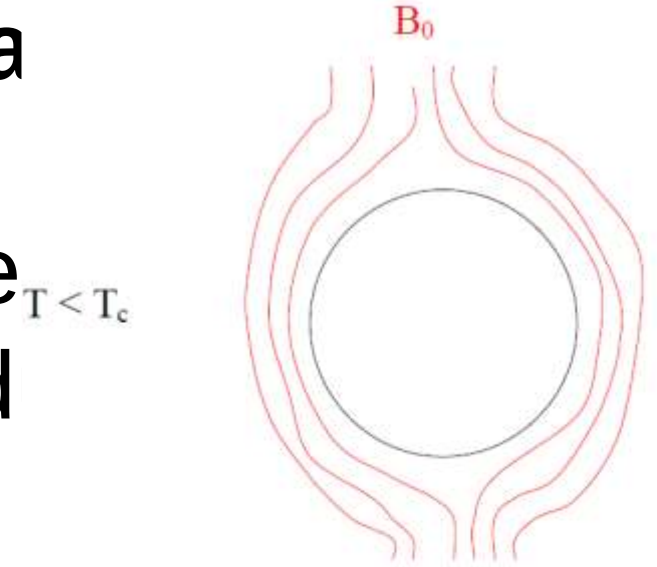
Field B inside material relates to Bo and magnetisation M of the material by

$B = B_o + \mu_o M$

in normal state M is esse



In superconducting sta



Field is excluded from supe

So field B inside supercond

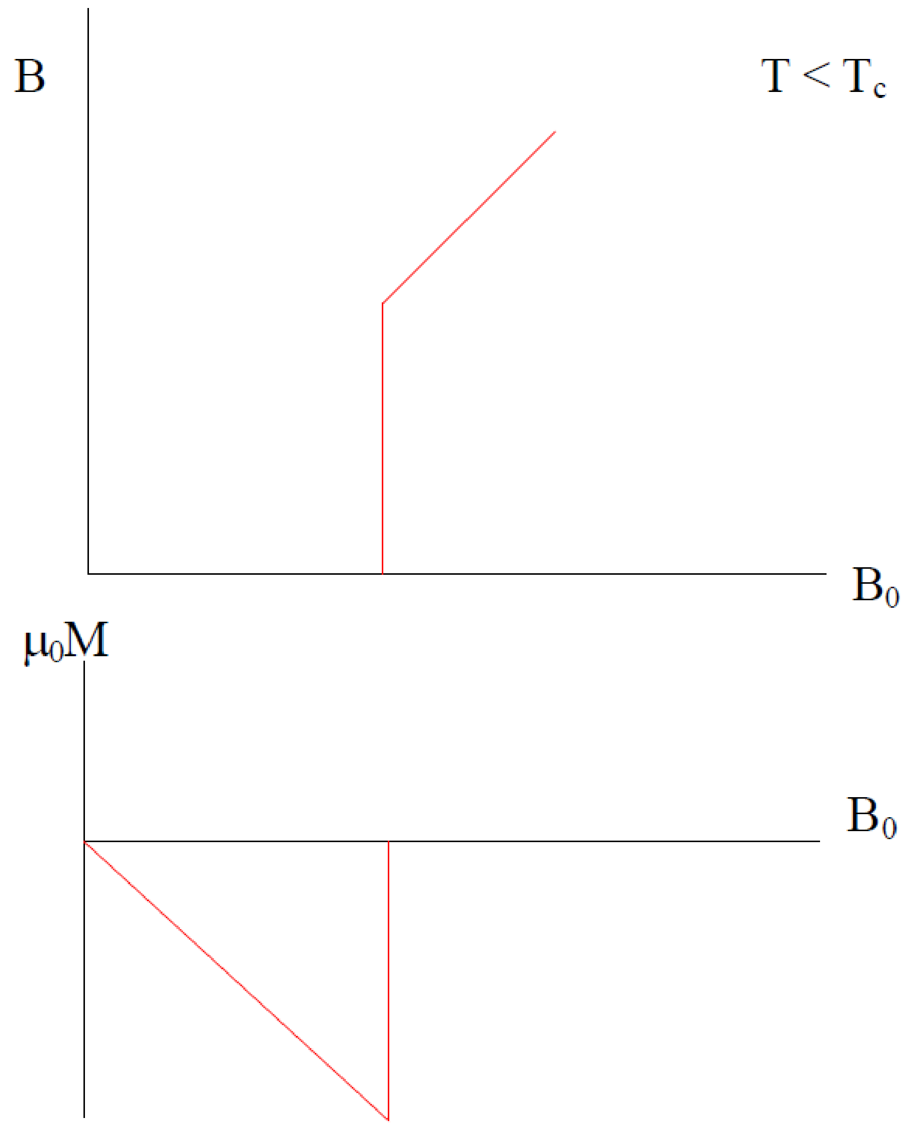
zero.

i.e. B = Bo + μoM = 0

→M = -Bo/μo

So magnetic susceptibility χ = μo M/Bo = -1

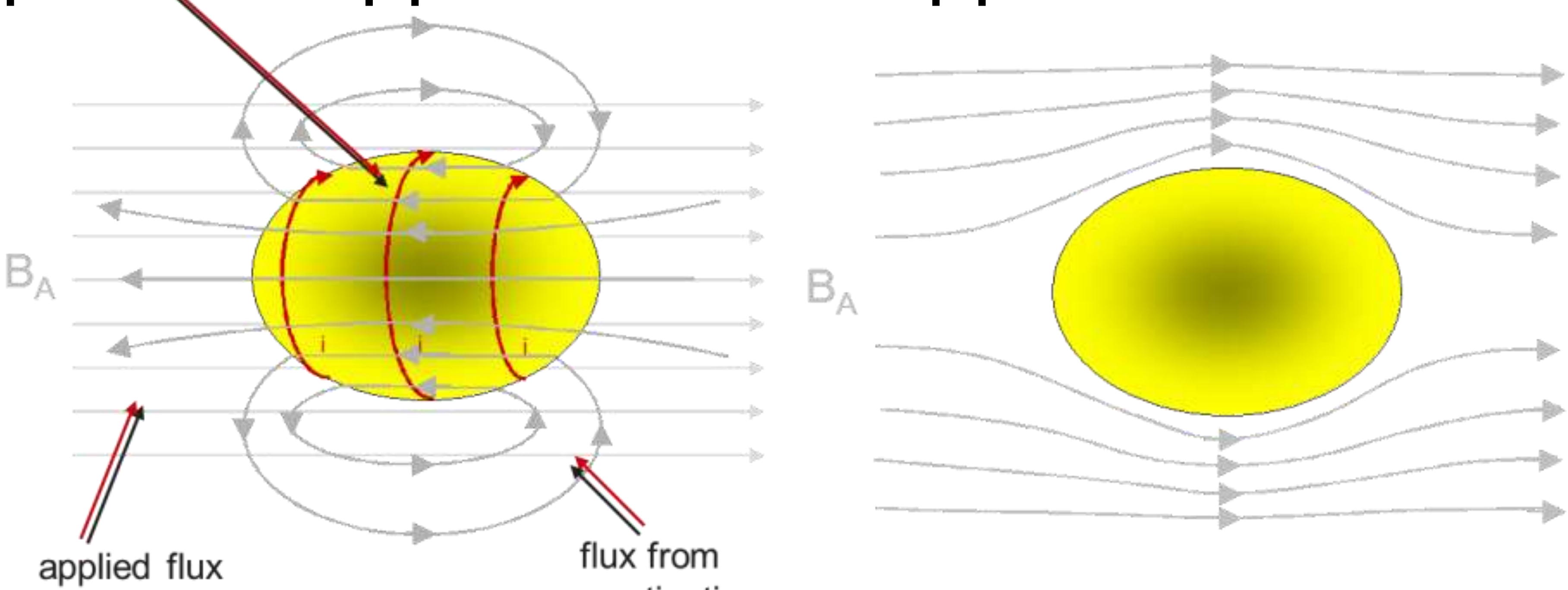
i.e. perfect diamagnetic



B
$T < T_c$
B_0
$\mu_0 M$
B_0

What’s actually happening?

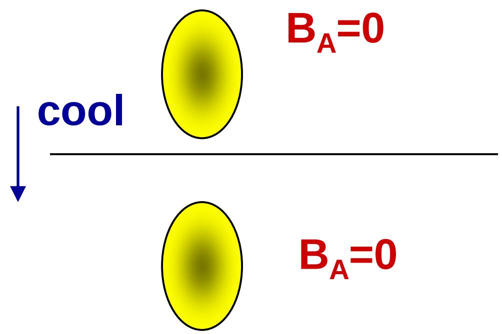
In the superconducting state:
screening currents flow on the surface of the superconductor in such a way as to generate a field inside the superconductor equal and opposite to the applied field.



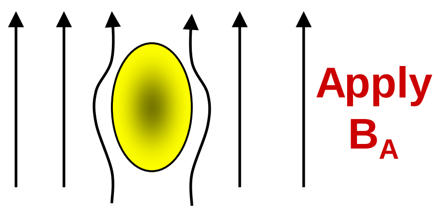
Does Meissner effect follow from ze

Meissner effect is treated as a seperate phenomena that must be explained *in addition* to the fact that the material has zero resistance.

A superconductor - cooled in zero field



The superconductor is cooled in zero magnetic flux density to below "T_c"

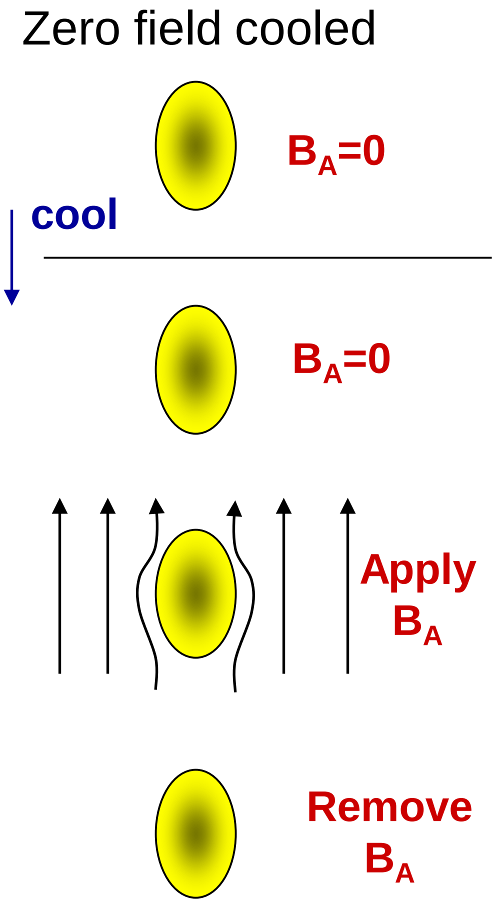


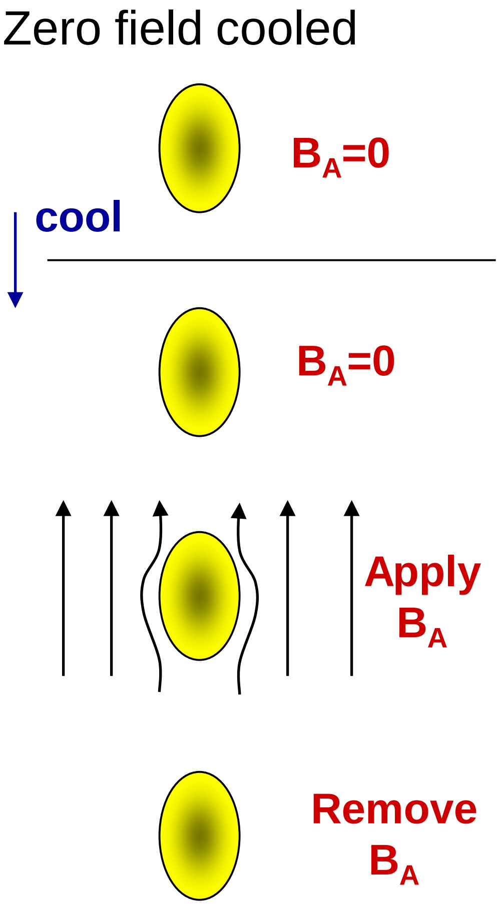
dB/dt must be zero in a closed resistanceless loop so screening currents flow to generate a field equal and opposite to B_A within the superconductor

As B_A is reduced to zero, dB/dt must remain at zero, so the screening currents also decrease to zero.

Precisely the same as a perfect conductor

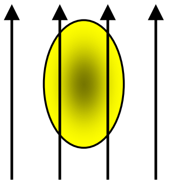
superconductor | perfect conductor



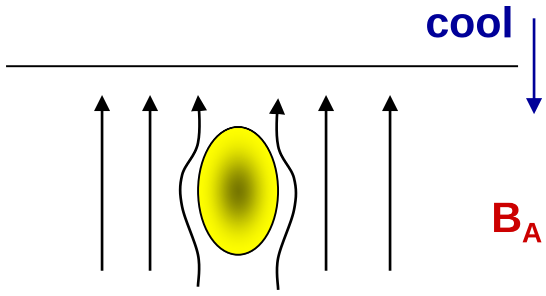


A superconductor” - cooled in a field

A magnetic flux density B_A is applied to the superconductor at high temperatures

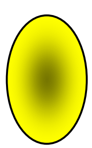


It is then cooled in a magnetic flux density B_A to below “T_c”



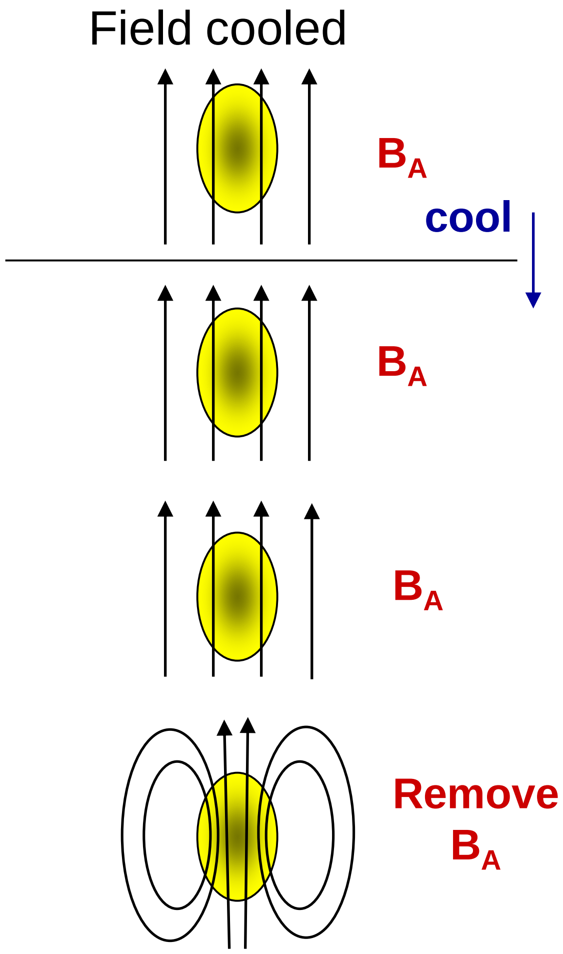
All magnetic flux is spontaneously excluded from the body of the superconductor - even though the applied flux density is unchanged and dB/dt=0 . Screening currents must therefore begin flow in a time invariant field to produce fields equal and opposite to B_A!!

As the applied magnetic flux density is reduced to zero, the screening currents also decrease to ensure that dB/dt=0 within the superconductor.

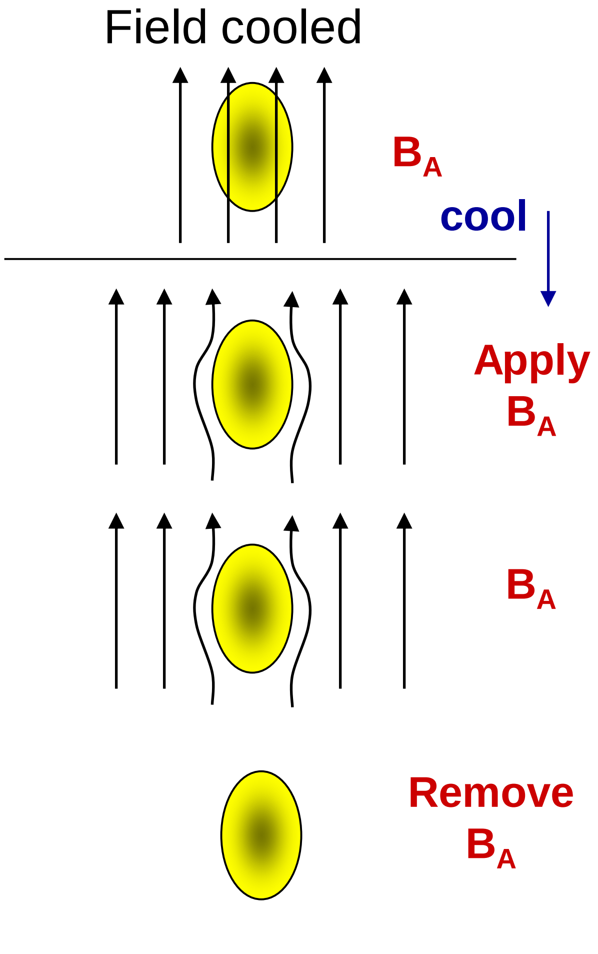


This is the Meissner Effect - it shows that not only must dB/dt=0 within a superconductor - but B itself must remain zero

perfect conductor



superconductor



The Meissner Effect - summary

Between 1911 and 1933 researchers considered that a superconductor was no more than a resistanceless perfect conductor

By measuring the properties of a superconductor cooled in a magnetic field they showed that not only

dB/dt=0 but also B=0

The ability of a superconductor to expel magnetic flux from its interior is the Meissner Effect

It is the first indication that the superconducting state is an entirely new state of matter

It shows that in a superconductor currents can be induced to flow in a

Superconductors are the materials that have almost zero resistivity and behave as diamagnetic below the