What Can We Do With a Quantum Liquid?

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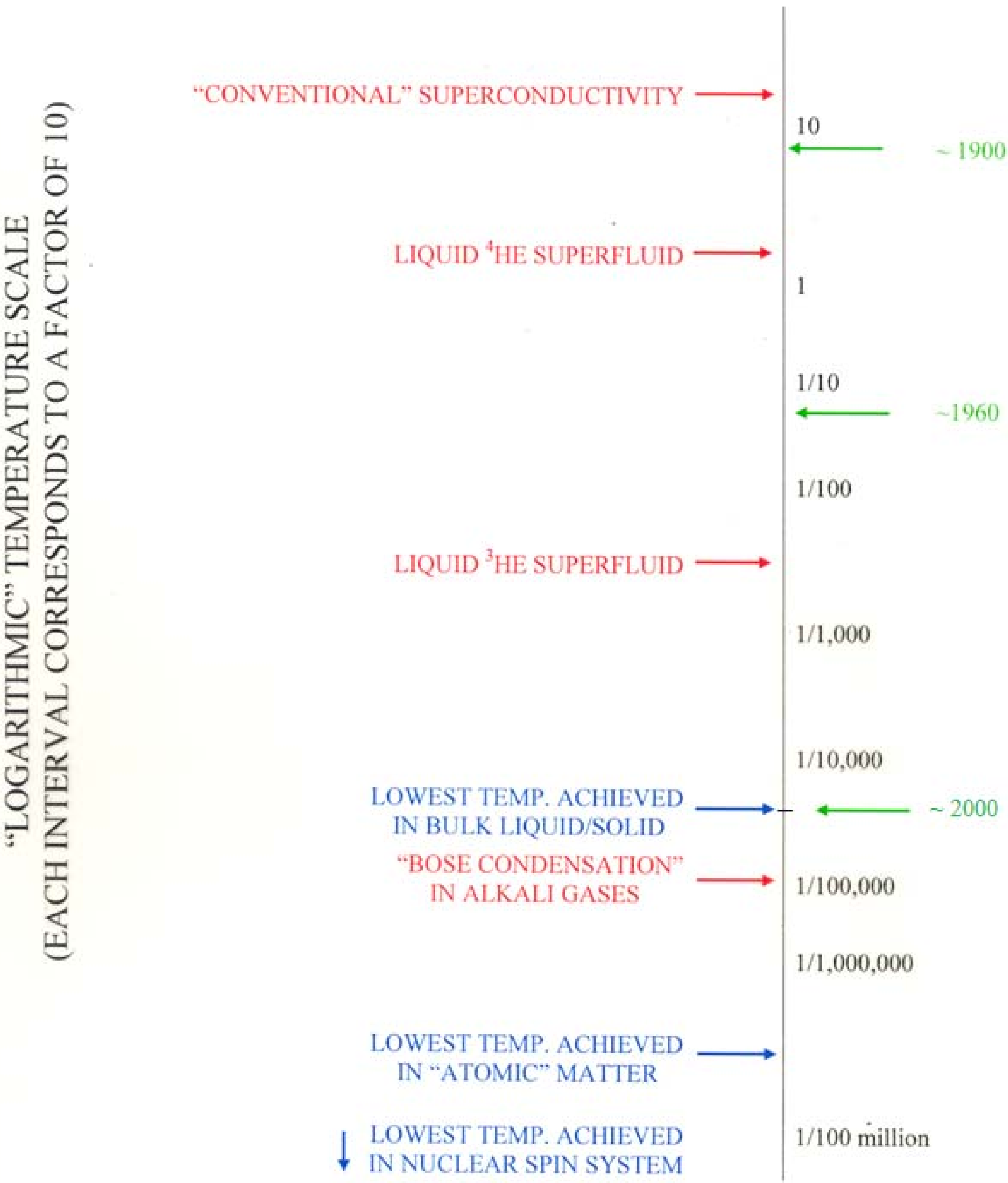
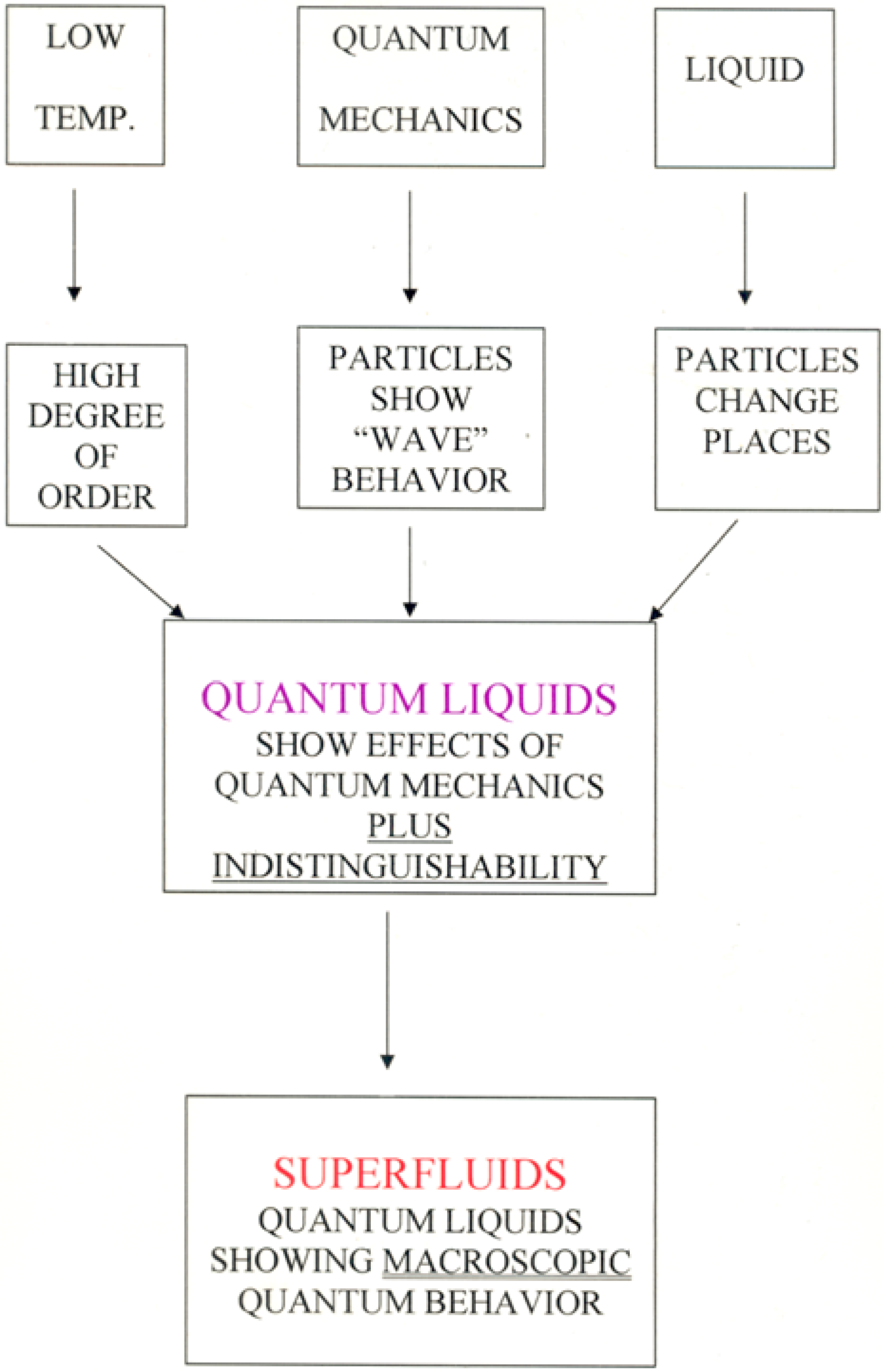
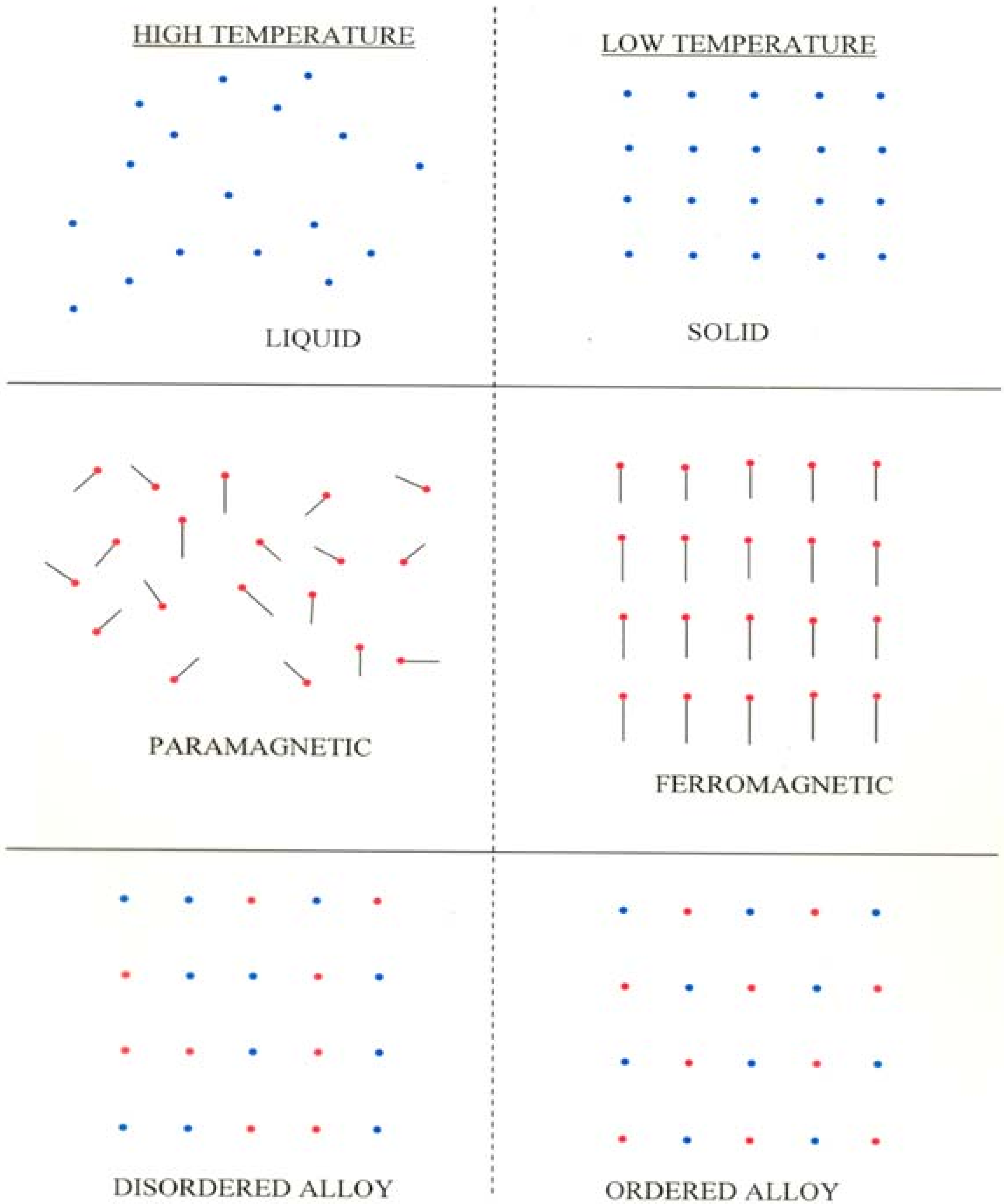
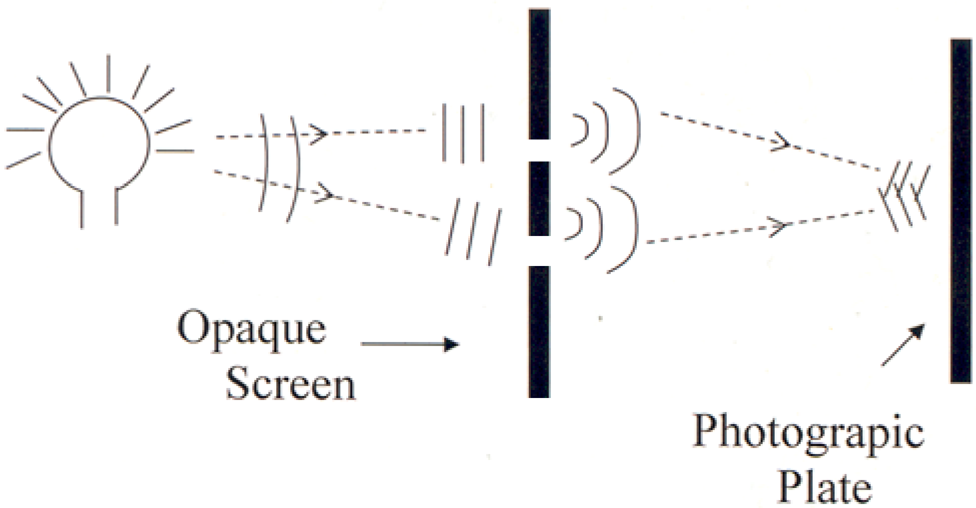

"LOGARITHMIC" TEMPERATURE SCALE
(EACH INTERVAL CORRESPONDS TO A FACTOR OF 10)
"CONVENTIONAL" SUPERCONDUCTIVITY
10
~ 1900
LIQUID ^{4}HE SUPERFLUID
1
1/10
~1960
1/100
LIQUID ^{3}HE SUPERFLUID
1/1,000
1/10,000
LOWEST TEMP. ACHIEVED IN BULK LIQUID/SOLID
~ 2000
"BOSE CONDENSATION" IN ALKALI GASES
1/100,000
1/1,000,000
LOWEST TEMP. ACHIEVED IN "ATOMIC" MATTER
LOWEST TEMP. ACHIEVED IN NUCLEAR SPIN SYSTEM
1/100 million


LOW TEMP.
QUANTUM MECHANICS
LIQUID
HIGH DEGREE OF ORDER
PARTICLES SHOW "WAVE" BEHAVIOR
PARTICLES CHANGE PLACES
QUANTUM LIQUIDS
SHOW EFFECTS OF QUANTUM MECHANICS PLUS INDISTINGUISHABILITY
SUPERFLUIDS
QUANTUM LIQUIDS SHOWING MACROSCOPIC QUANTUM BEHAVIOR

TEMPERATURE, ORDER and DISORDER



PARTICLES AS WAVES

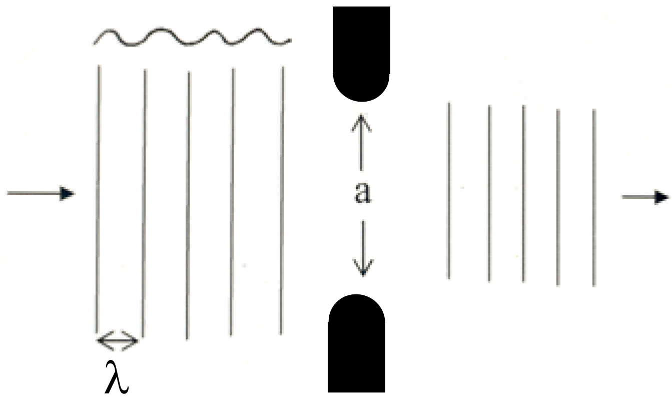


Quantitative particle-wave relation
("de Broglie relation"):

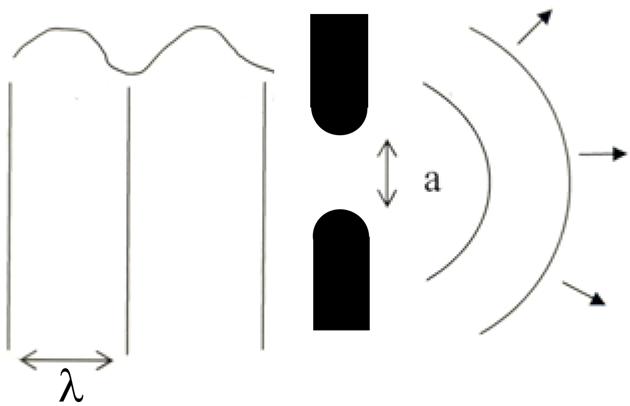
$$\lambda = h/mv$$

- λ: wavelength (wave property)
- h: Planck's constant, ~ 6 x 10^{-34} joule secs
- m: mass (particle properties)
- v: velocity (particle properties)

When does a "wave" behave like a "particle"?



$\lambda \ll a$:
No diffraction:
"Particle-like"



$\lambda \gtrsim a$
Diffraction and interference

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since $\lambda = h/mv$ (De Broglie) to get $\lambda \gtrsim a$ need

$v \lesssim h/ma$: but $\frac{1}{2}mv^2 \sim k_B T$

so to see "wave" effects need

$$\boxed{T \lesssim h^2/2mk_B a^2}$$

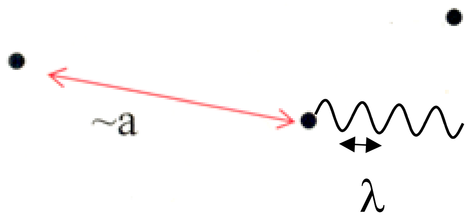
Boltzmann's constant, $\sim 10^{-23}$ joules/degree

In a gas/liquid/solid, take "slit width" a ~ interparticle spacing

$\Rightarrow$ to get "wavelike" behavior, need (for atoms)
$T \lesssim 20°K/(\text{atomic number})$

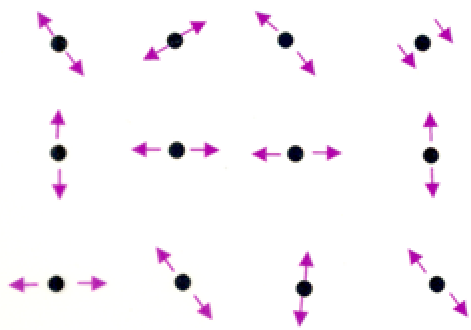
(electrons show "wavelike" behavior for all T in liquid/solid phase)

Why "Quantum Liquids"?



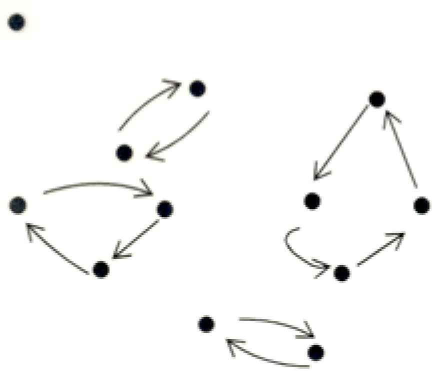
Gas: (usually)

$\lambda \ll a$
so no "wave"
(quantum) effects



Solid at low T:

$\lambda \gtrsim a$ but atoms
don't change places



Liquid at low T:

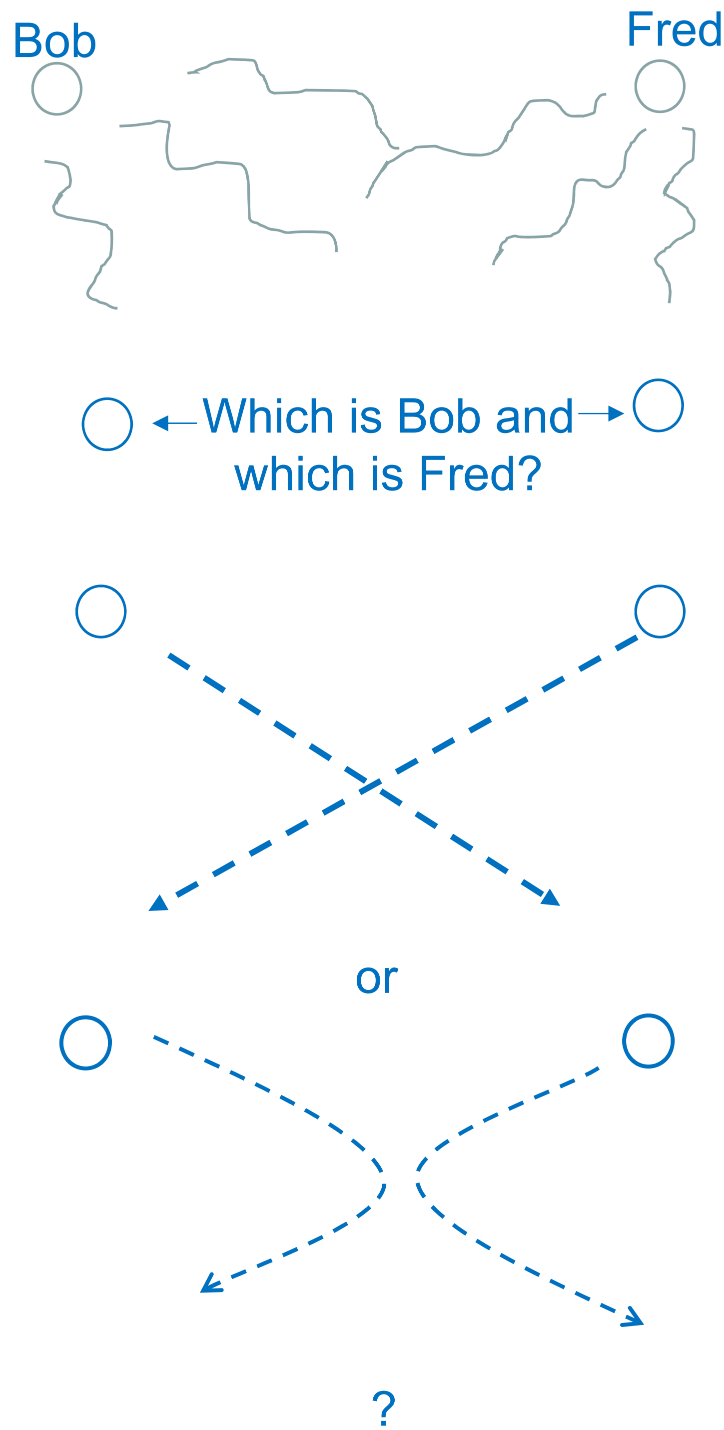
$\lambda \gtrsim a$ and
atoms change places

need: $T \lesssim 20°$ K/(atomic no.) and liquid!

Atoms: helium (and ultracold atomic gases)
Electrons: all liquid/solid metals

Indistinguishablity of elementary particles

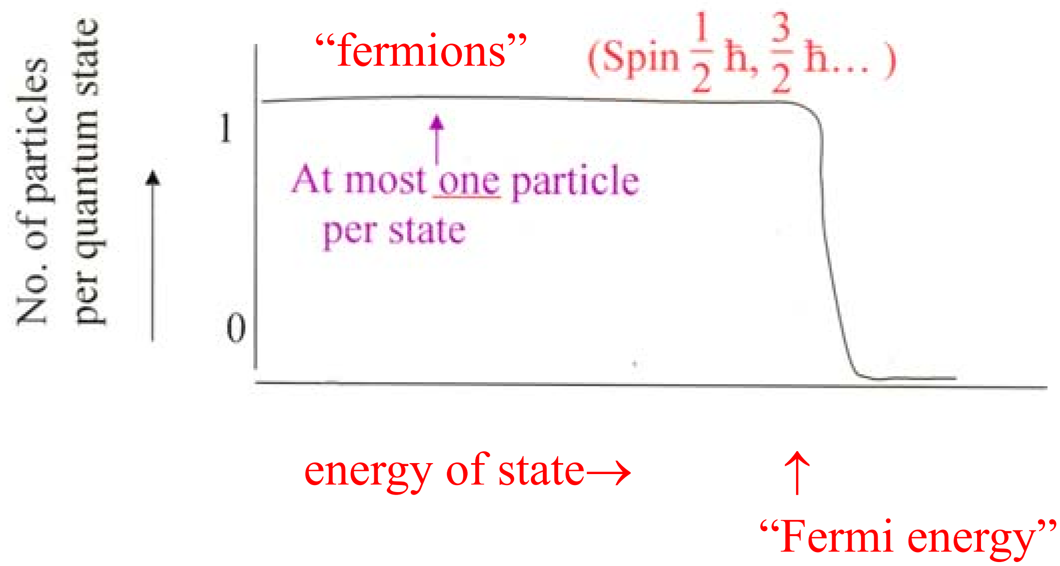
Because particles behave like waves, impossible to “tag” them.

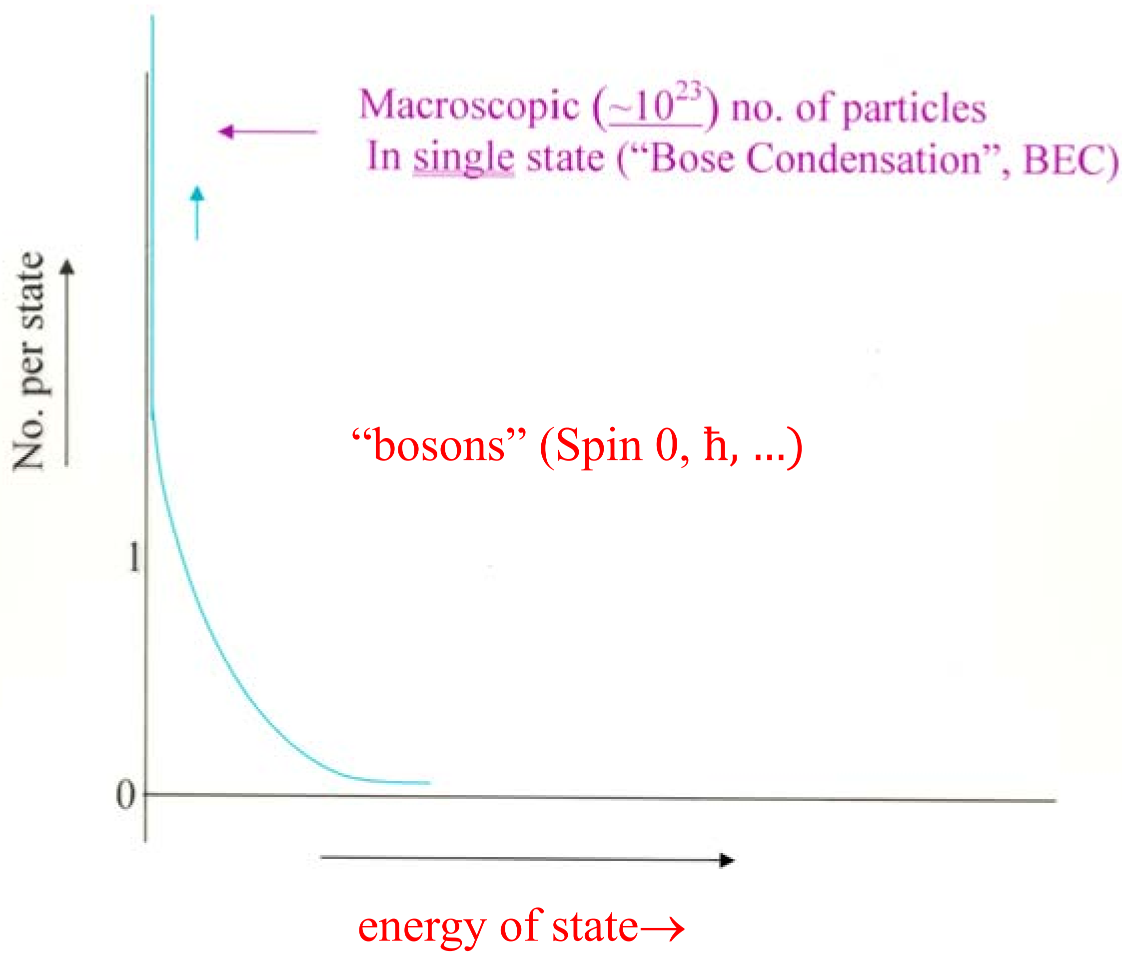


Evidently, for this property to be important, must be able to change places

Result of indistinguishability:

"QUANTUM STATISTICS"



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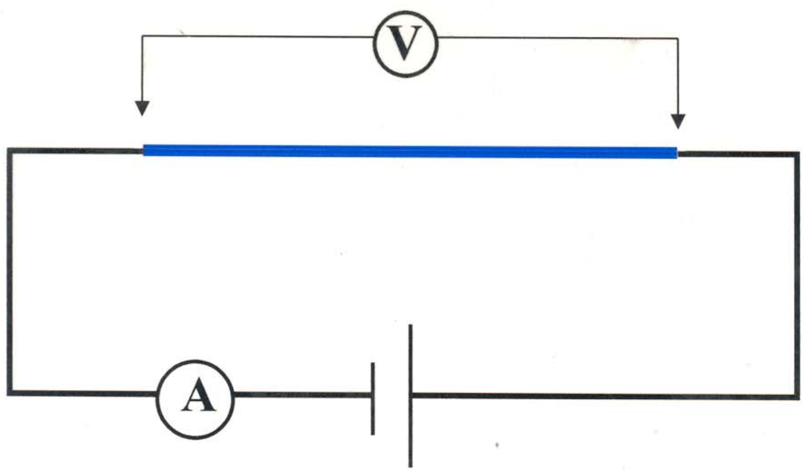
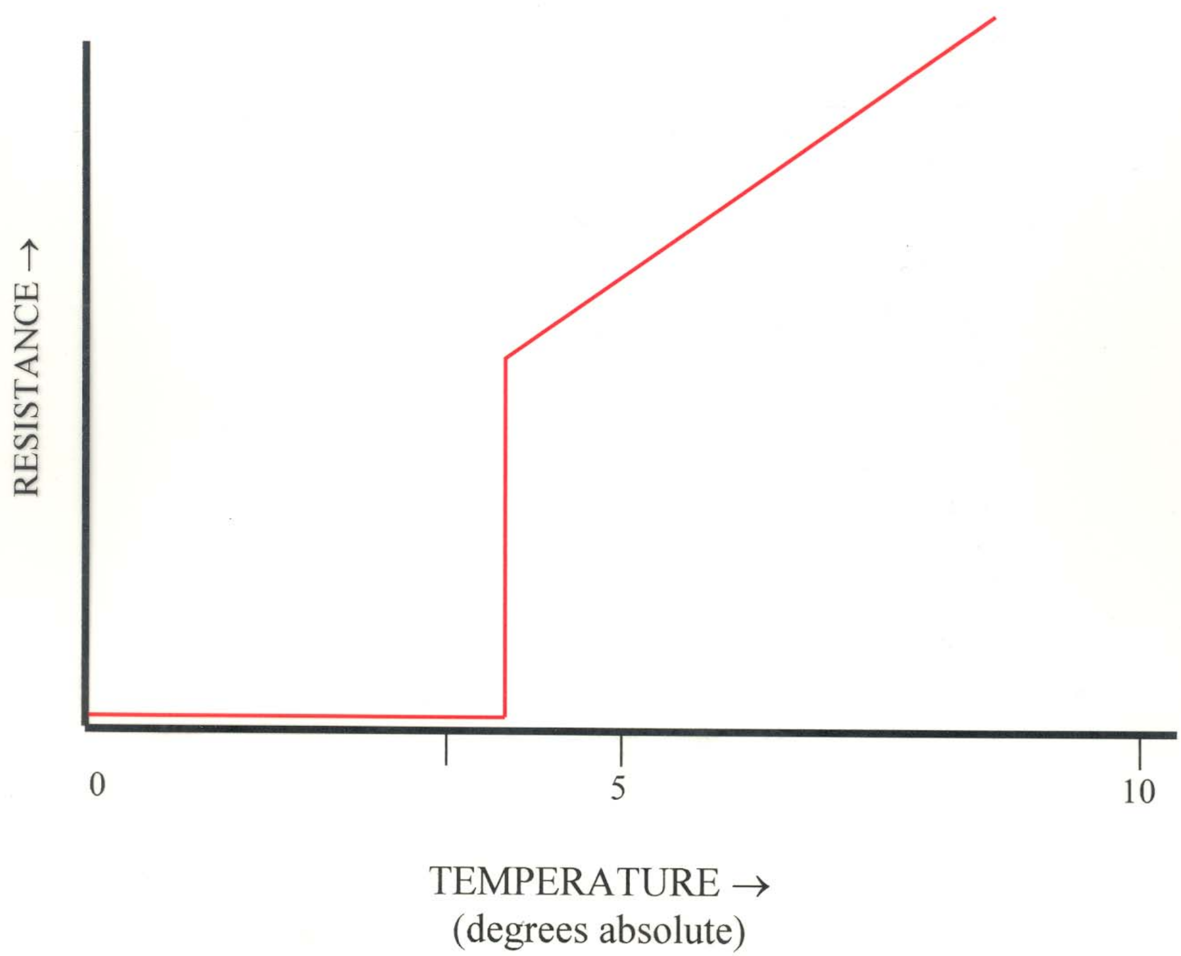
Molecule of the Year
the Bose-Einstein Condensate

Superconductivity

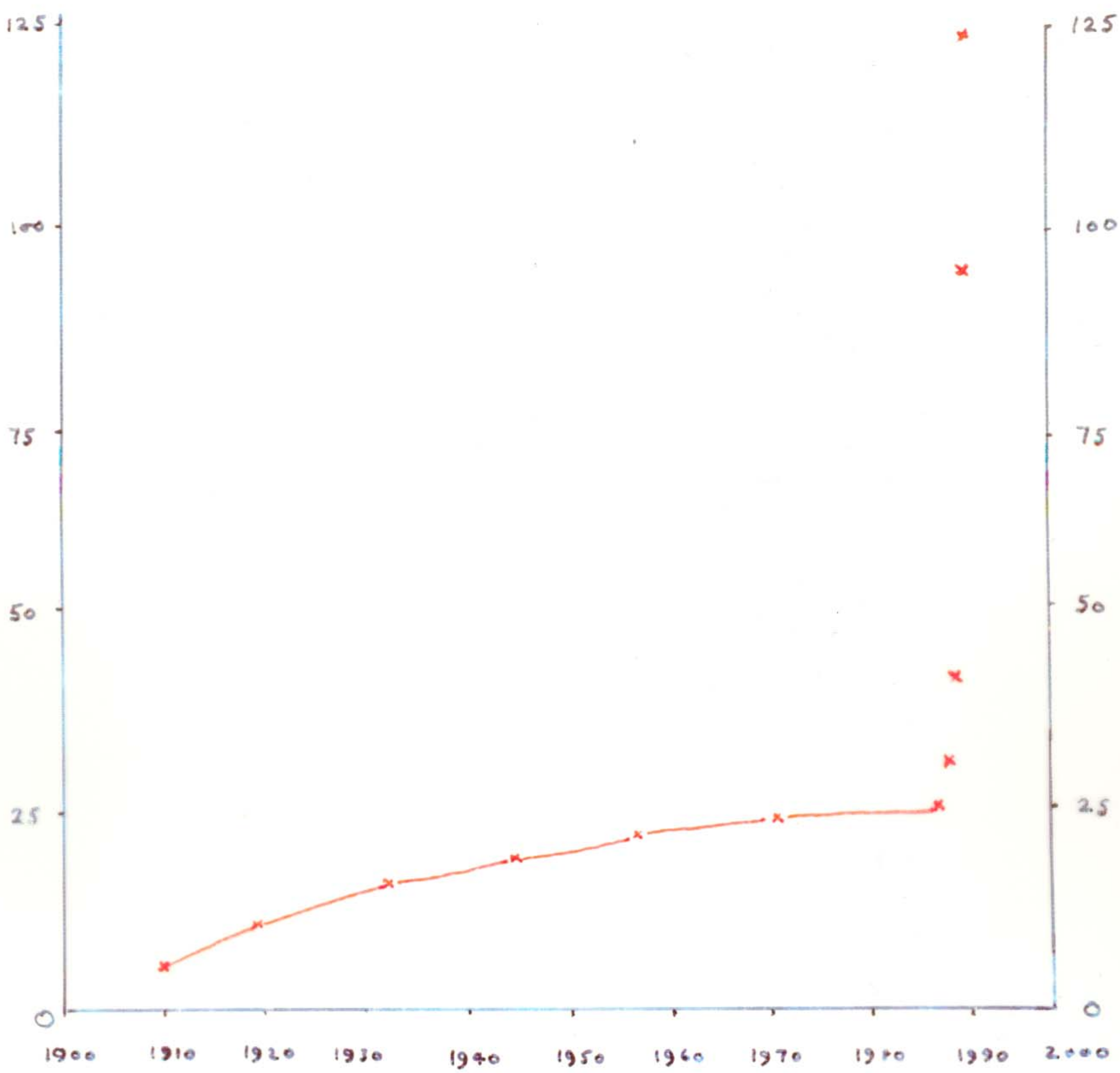


resistance of ▬ = V/A = voltage/current



2014

HISTORY OF THE HIGHEST TEMPERATURE ("T_c") AT WHICH SUPERCONDUCTIVITY KNOWN



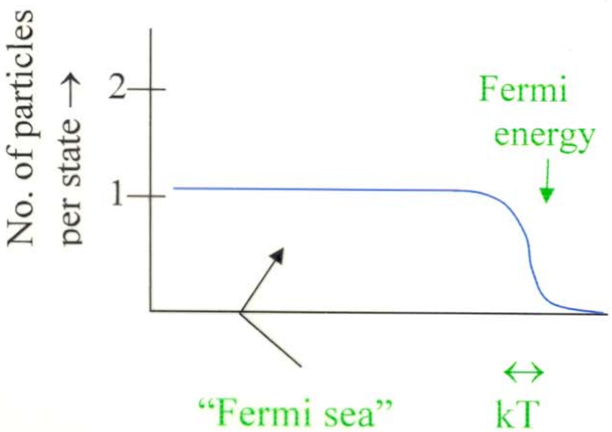
PHYSICS OF SUPERCONDUCTIVITY

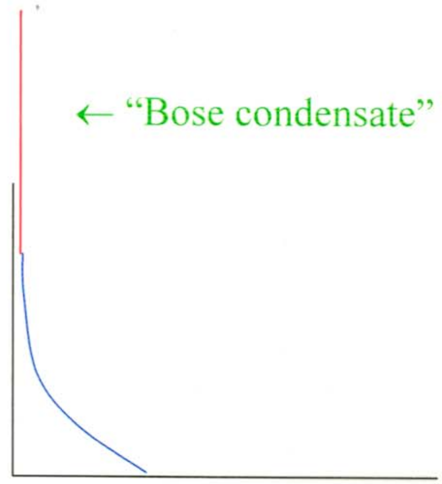
"Spin" of elementary particles $= \frac{n}{2}\,\hbar$

0, 1, 2.... bosons

$\frac{1}{2}, \frac{3}{2}, \frac{5}{2}$.... fermions

At low temperatures:





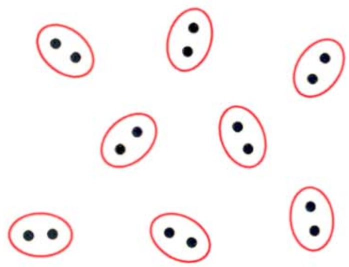
Electrons in metals: spin ½ ⇒ fermions

But a compound object consisting of an even no. of fermions has spin 0, 1, 2 … ⇒ boson.

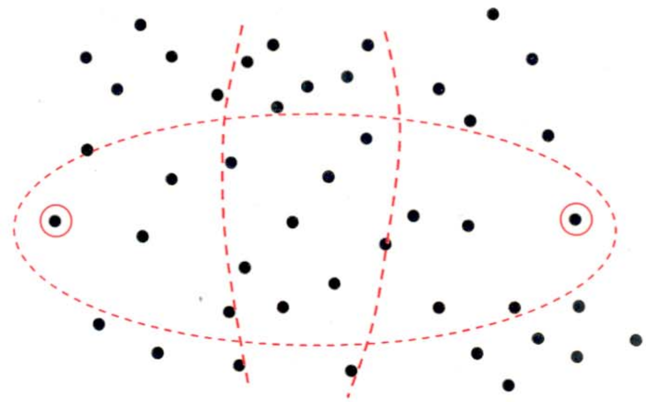
(Ex: $2p + 2n + 2e = {}^{4}He$ atom)

⇒ can undergo Bose condensation

Pairing of electrons:



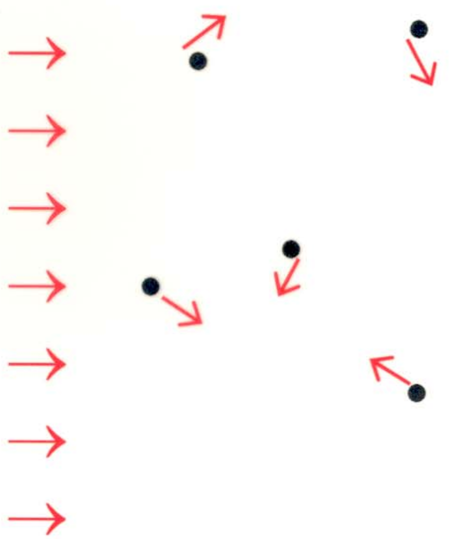
"di-electronic molecules"



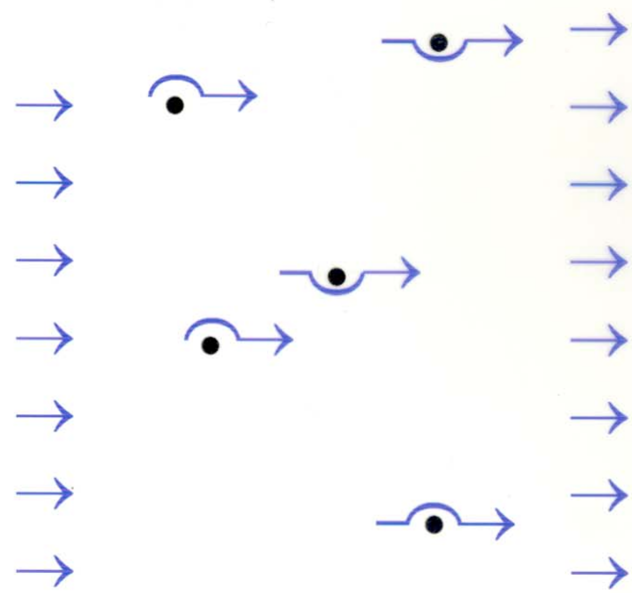
Cooper Pairs

In simplest ("BCS") theory, Cooper pairs, once formed, must automatically undergo Bose condensation!

⇒ must all do exactly the same thing at the same time (also in nonequilibrium situation)



Single electrons in normal metal



Cooper pairs in superconductor