Title: Anthony Leggett - Thoughts on the future of Physics.

Date: Oct 02, 2004 02:00 PM

URL: http://pirsa.org/04100003

Abstract: 2003 Nobel Prize Winner shares thoughts on the future of physics. <kw>Anthony Leggett, quantum mechanics, wave, particle, quantum liquids, superconductivity, De Broglie relation, Cooper\'s pair, Schrodinger cat, many-bodies </kw>

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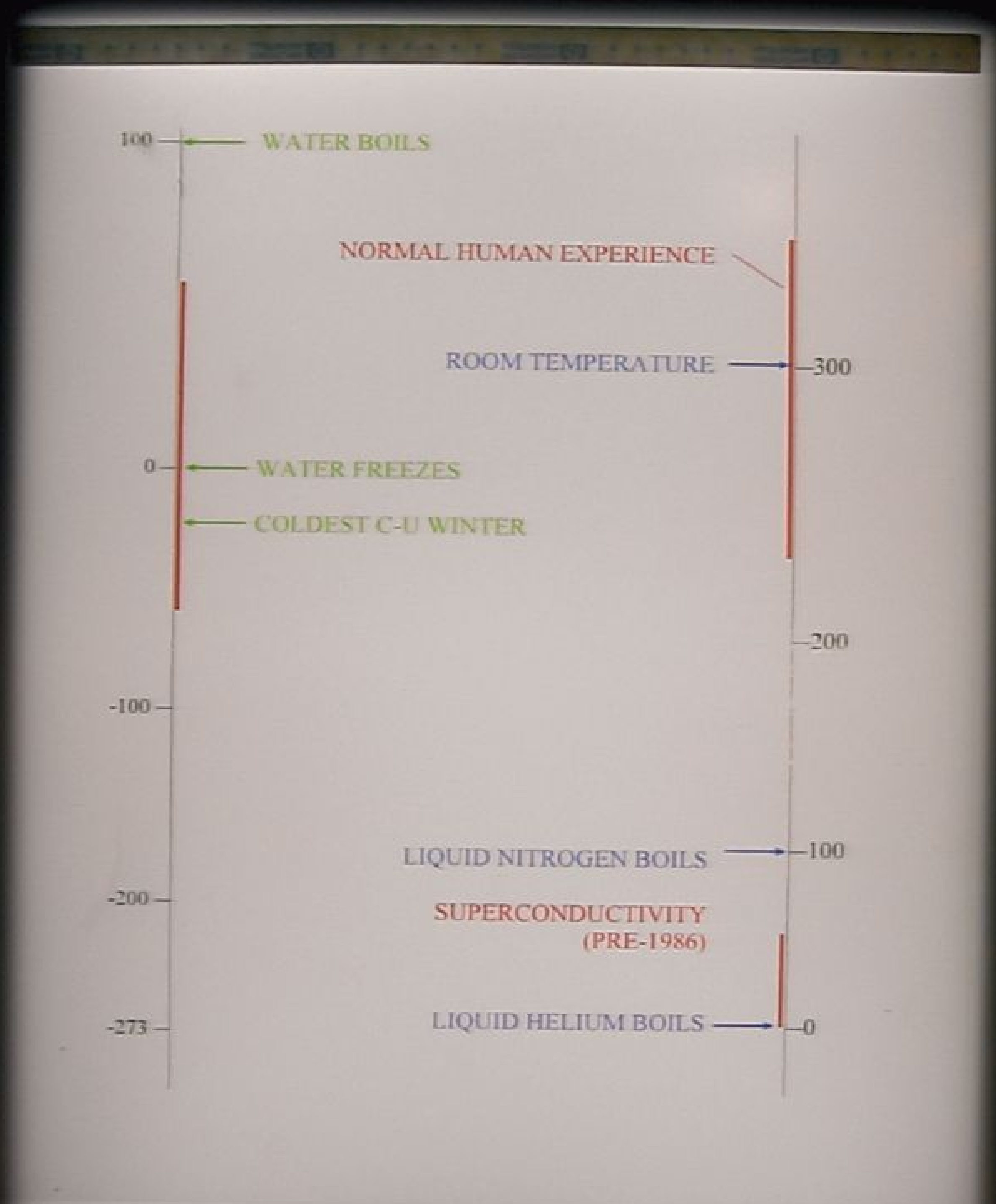
FOR THEORETICAL PHYSICS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NORMAL HUMAN EXPERIENCE
ROOM TEMPERATURE
300
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WATER FREEZES
COLDEST C-U WINTER
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LIQUID NITROGEN BOILS
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-200
SUPERCONDUCTIVITY
(PRE-1986)
-273
LIQUID HELIUM BOILS
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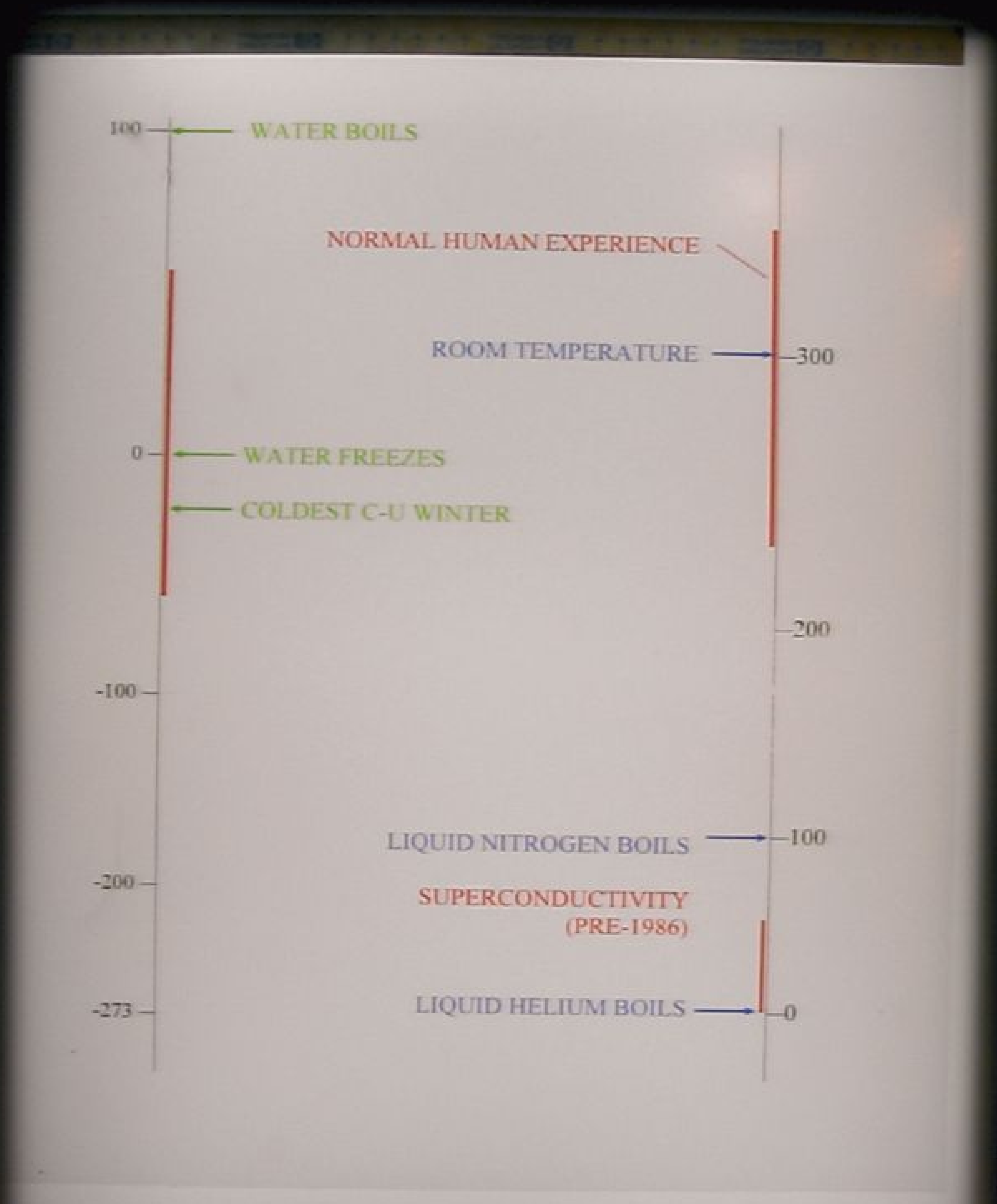
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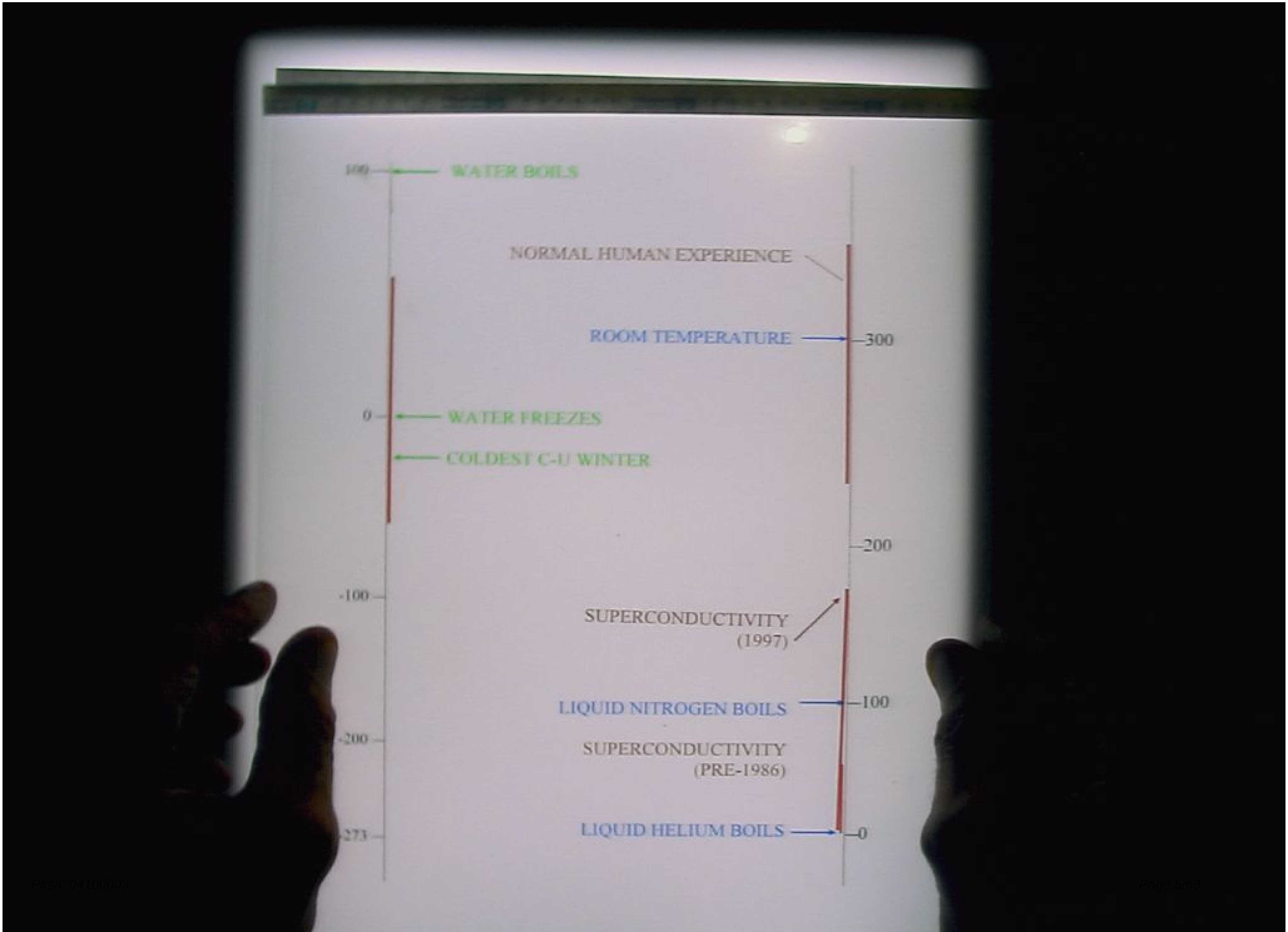
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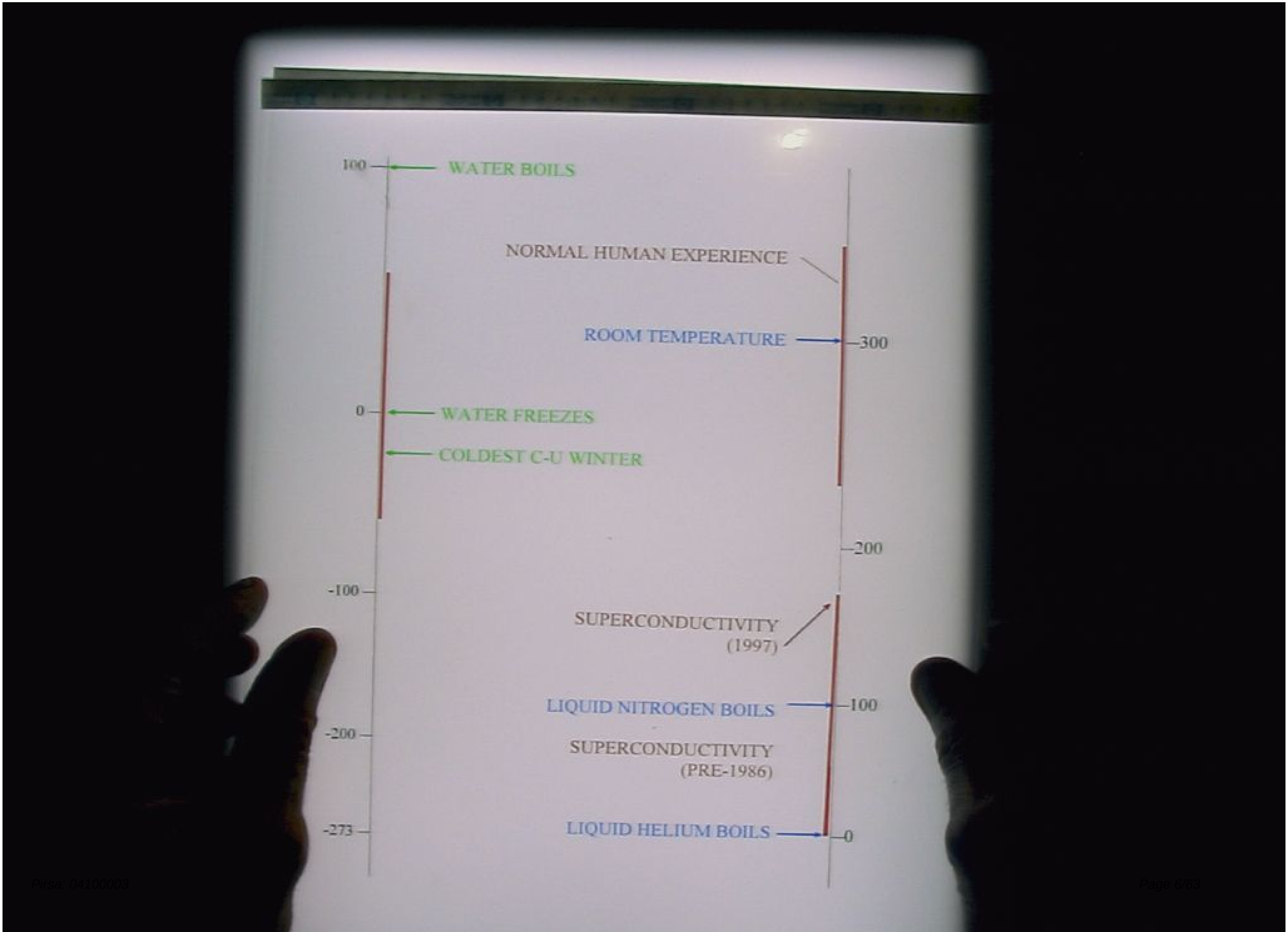
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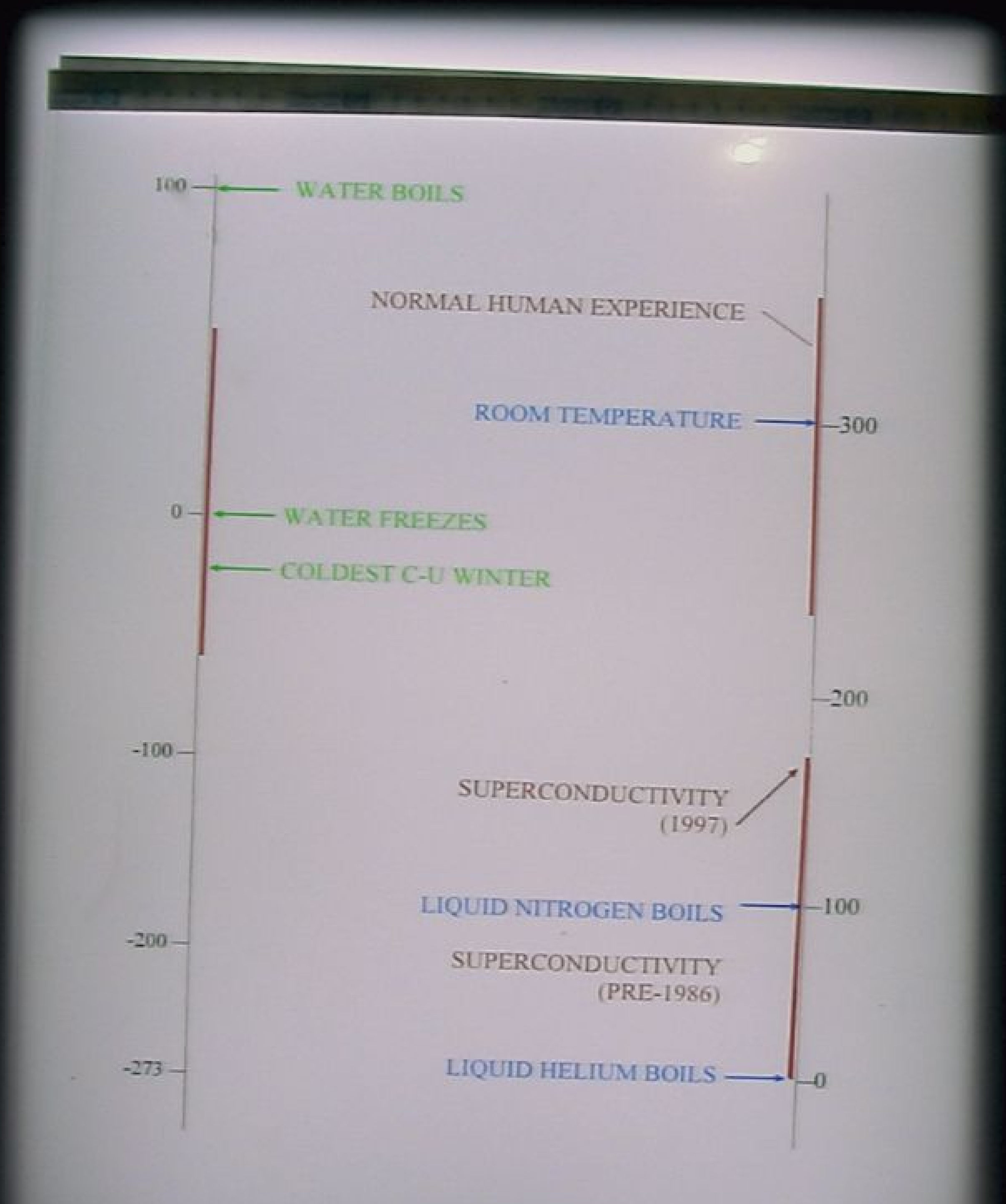
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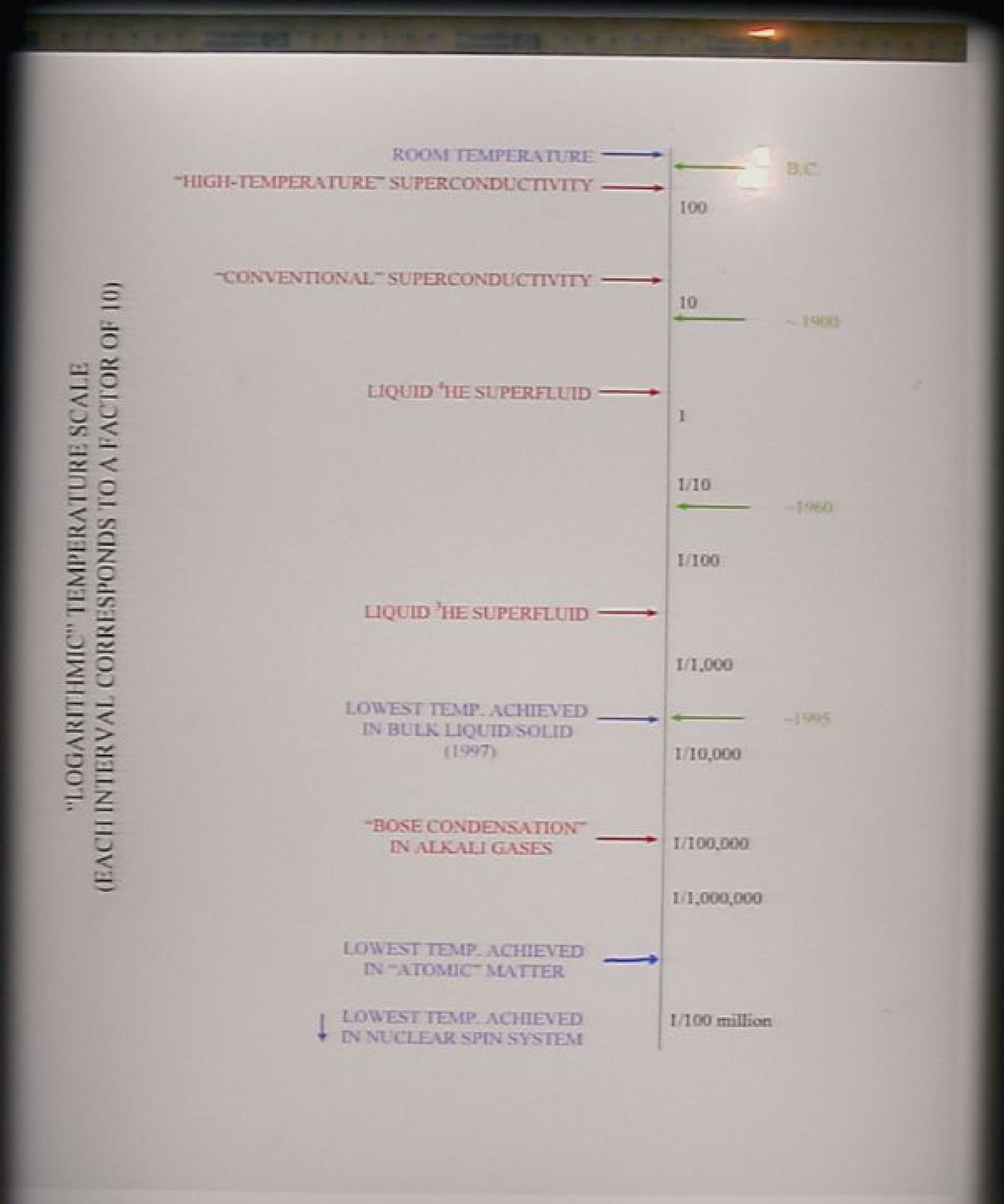
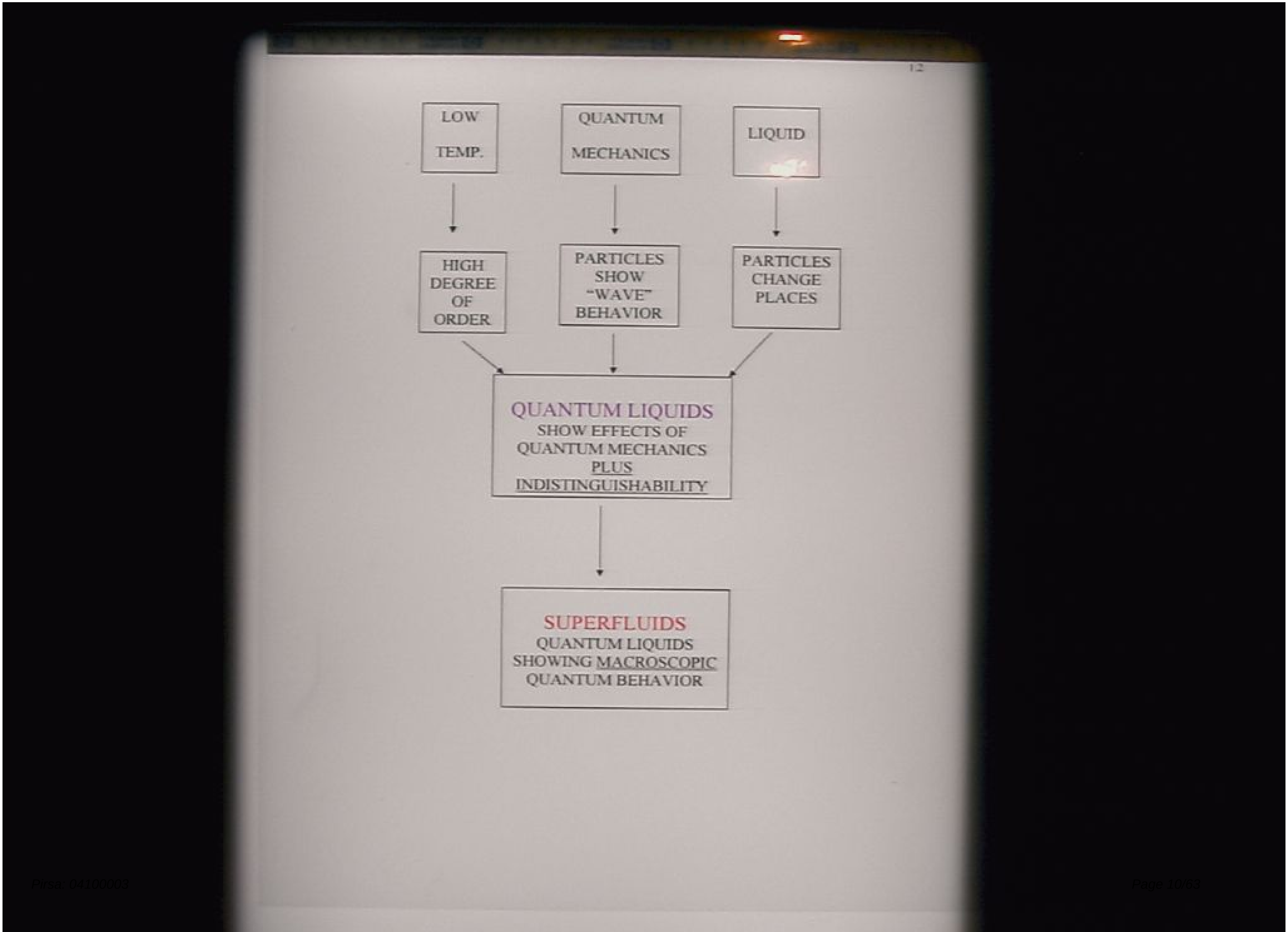
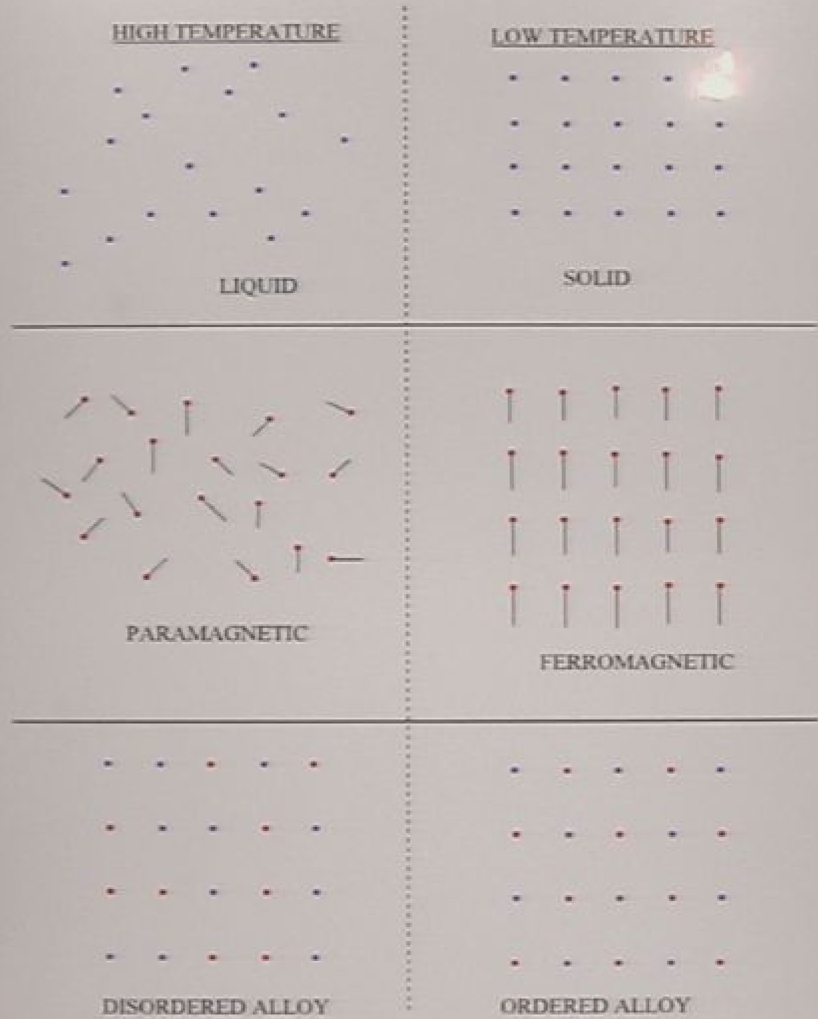
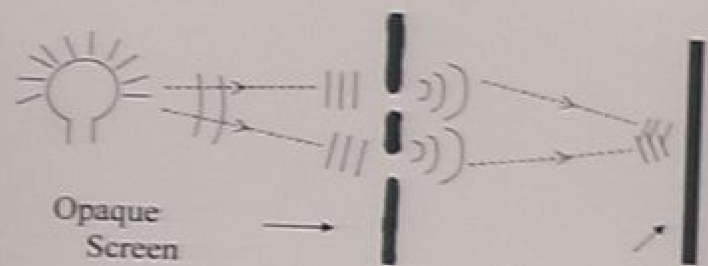

"LOGARITHMIC" TEMPERATURE SCALE
(EACH INTERVAL CORRESPONDS TO A FACTOR OF 10)
ROOM TEMPERATURE
"HIGH-TEMPERATURE" SUPERCONDUCTIVITY
B.C.
100
"CONVENTIONAL" SUPERCONDUCTIVITY
10
~1900
LIQUID ^{4}HE SUPERFLUID
1
1/10
~1960
1/100
LIQUID ^{3}HE SUPERFLUID
1/1,000
LOWEST TEMP. ACHIEVED IN BULK LIQUID/SOLID (1997)
~1995
1/10,000
"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


12
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



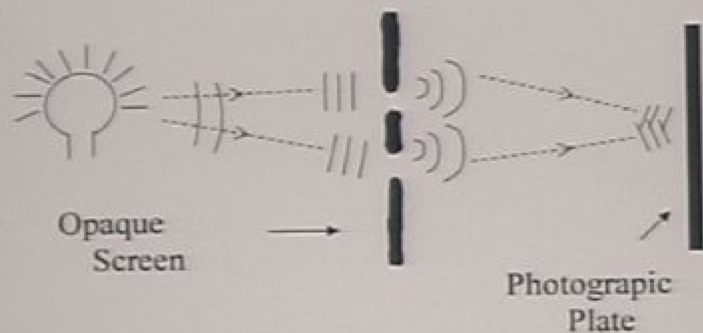
For Particles:

$$\boxed{\lambda = h/mv}$$

Wavelength

"DE BROGLIE RELATION"

PARTICLES AS WAVES



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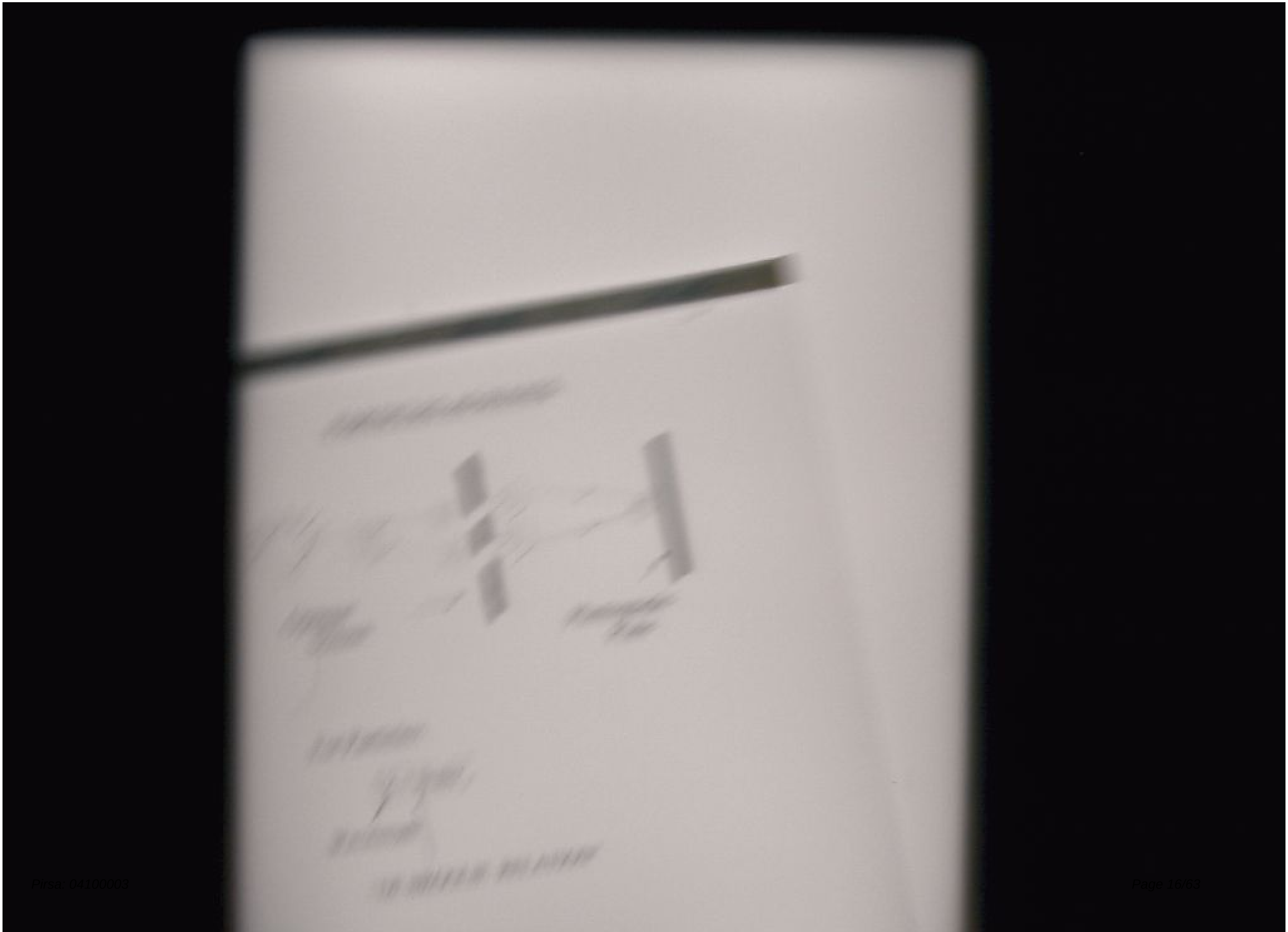
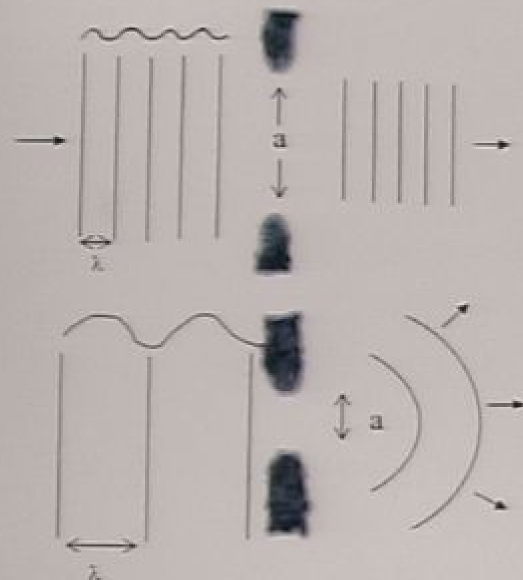
$\lambda = h/mv$

Wavelength

"DE BROGLIE RELATION"



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



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

$\lambda \gtrsim a$:
Diffraction and
Interference

---

since $\lambda = h/mv$ (De Broglie) need

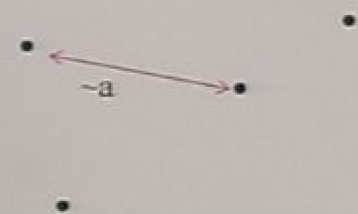
$$v \lesssim h/ma: \text{ but } \frac{1}{2}mv^2 \sim k_B T$$

so to see "wave" effects need

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

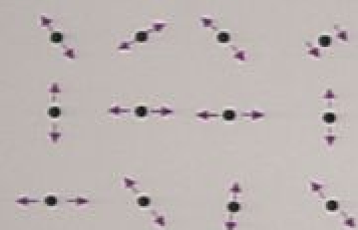
Boltzmann's constant

Why "Quantum Liquids"?



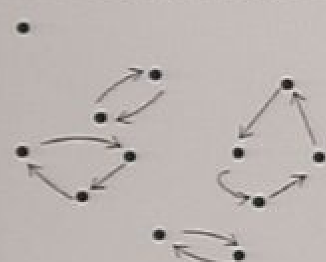
Gas: (usually)

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



Solid at low T:

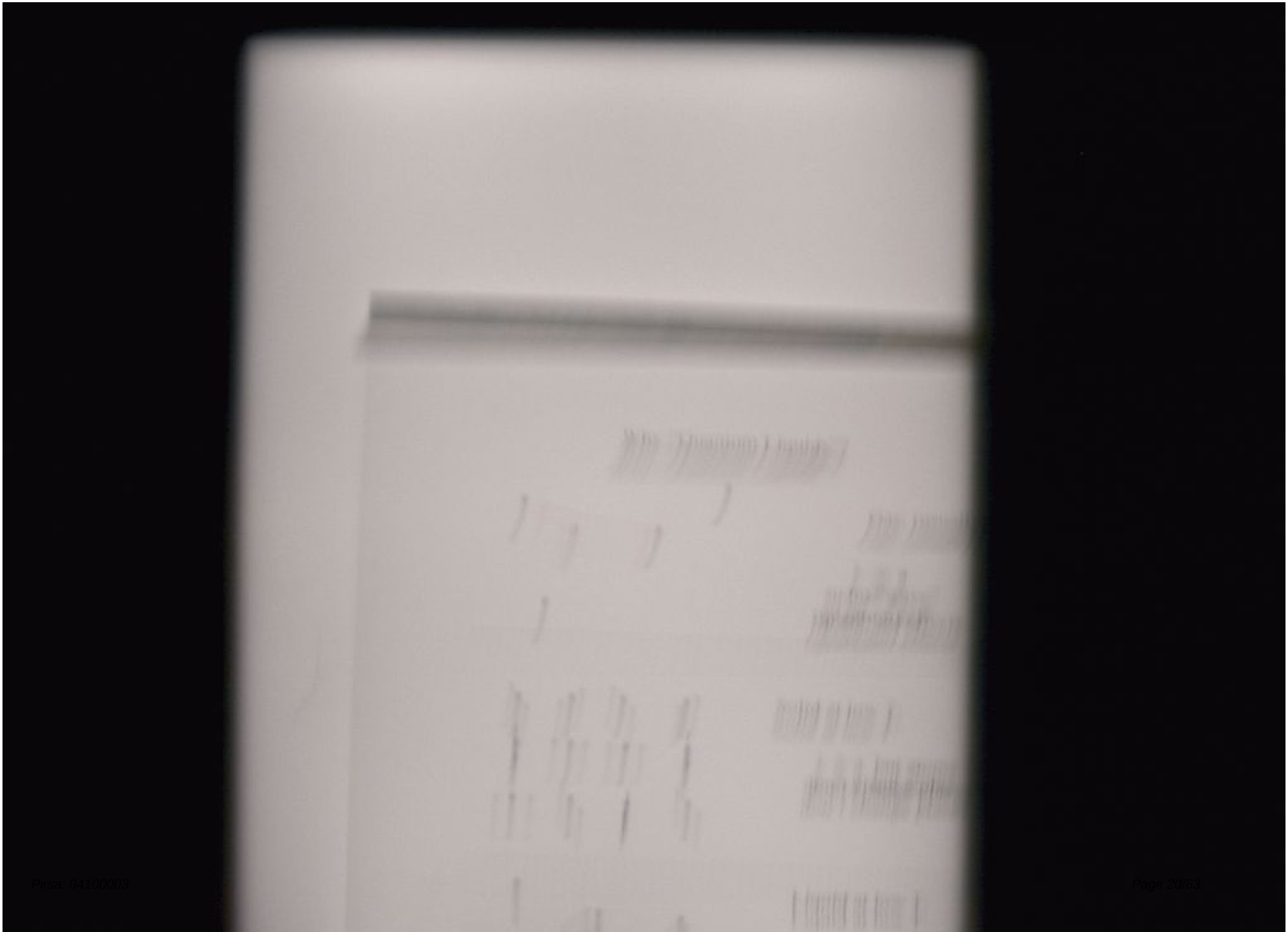
$\lambda \gtrsim a$ but atoms
don't change places



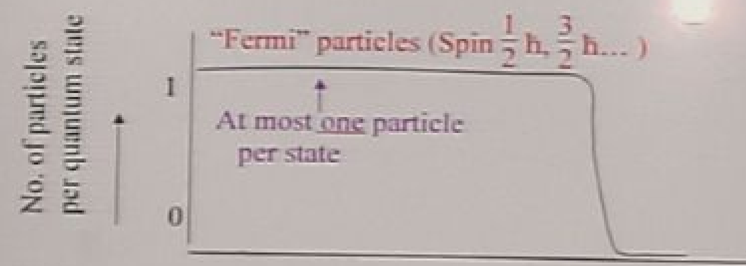
Liquid at low T:

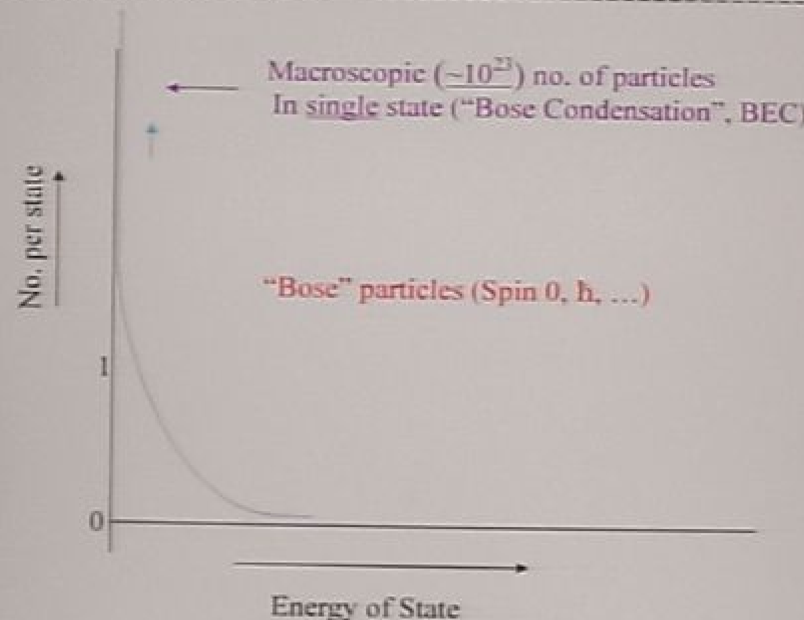
$\lambda \gtrsim a$ <u>and</u>
atoms change places

$T \lesssim 20° K/(\text{Atomic No.})$



"QUANTUM STATISTICS"



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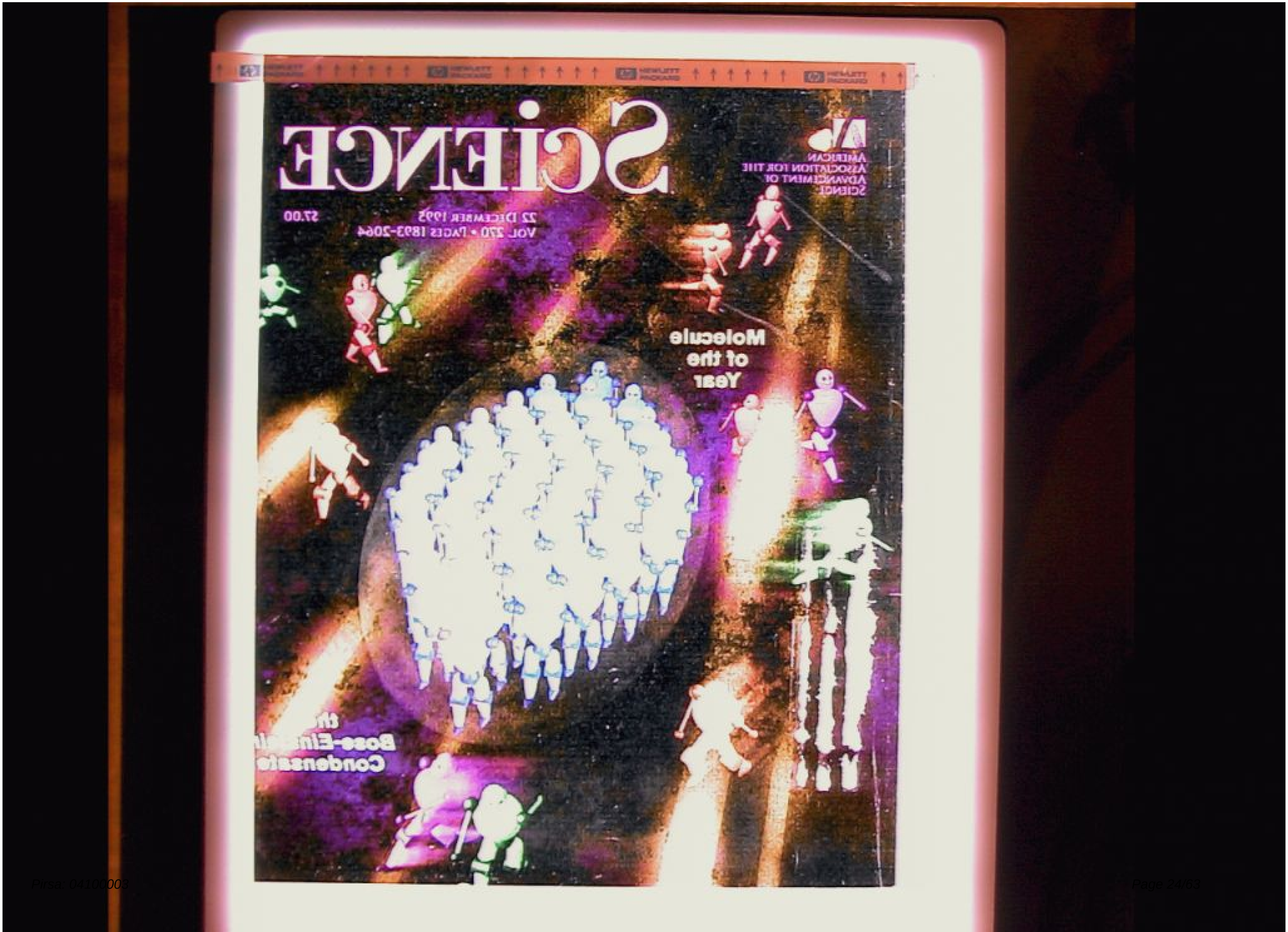
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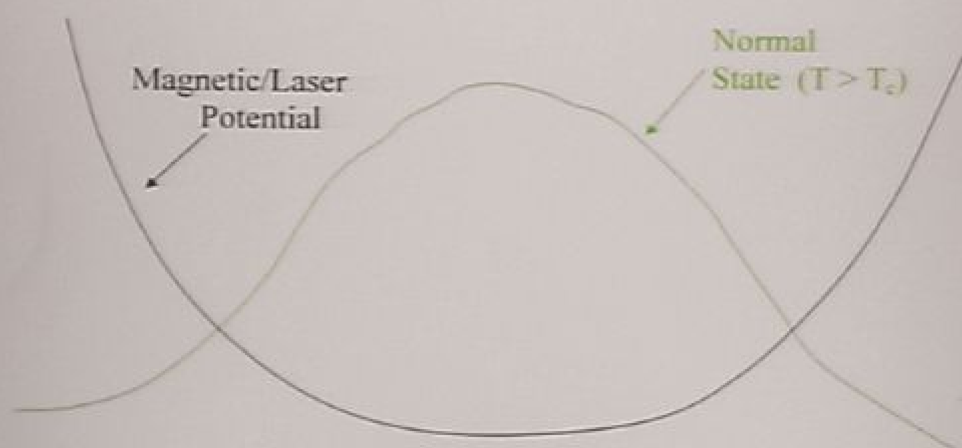
HOW TO SEE BEC OCCURRING?

LITERALLY



HOW TO SEE BEC OCCURRING?

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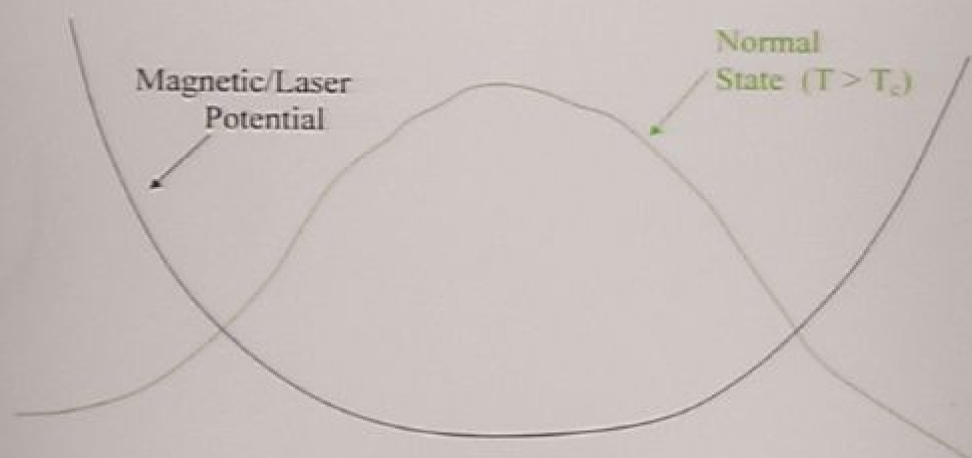
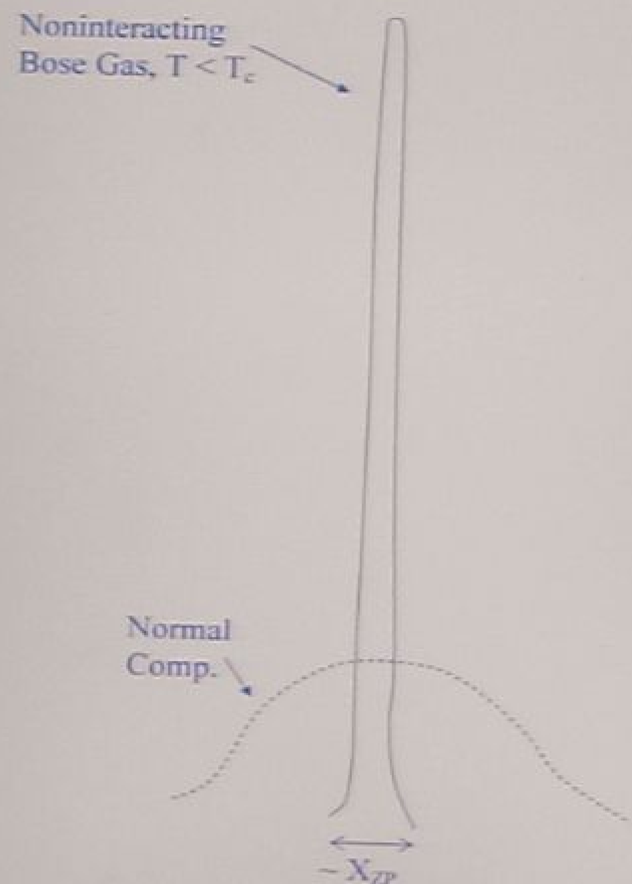
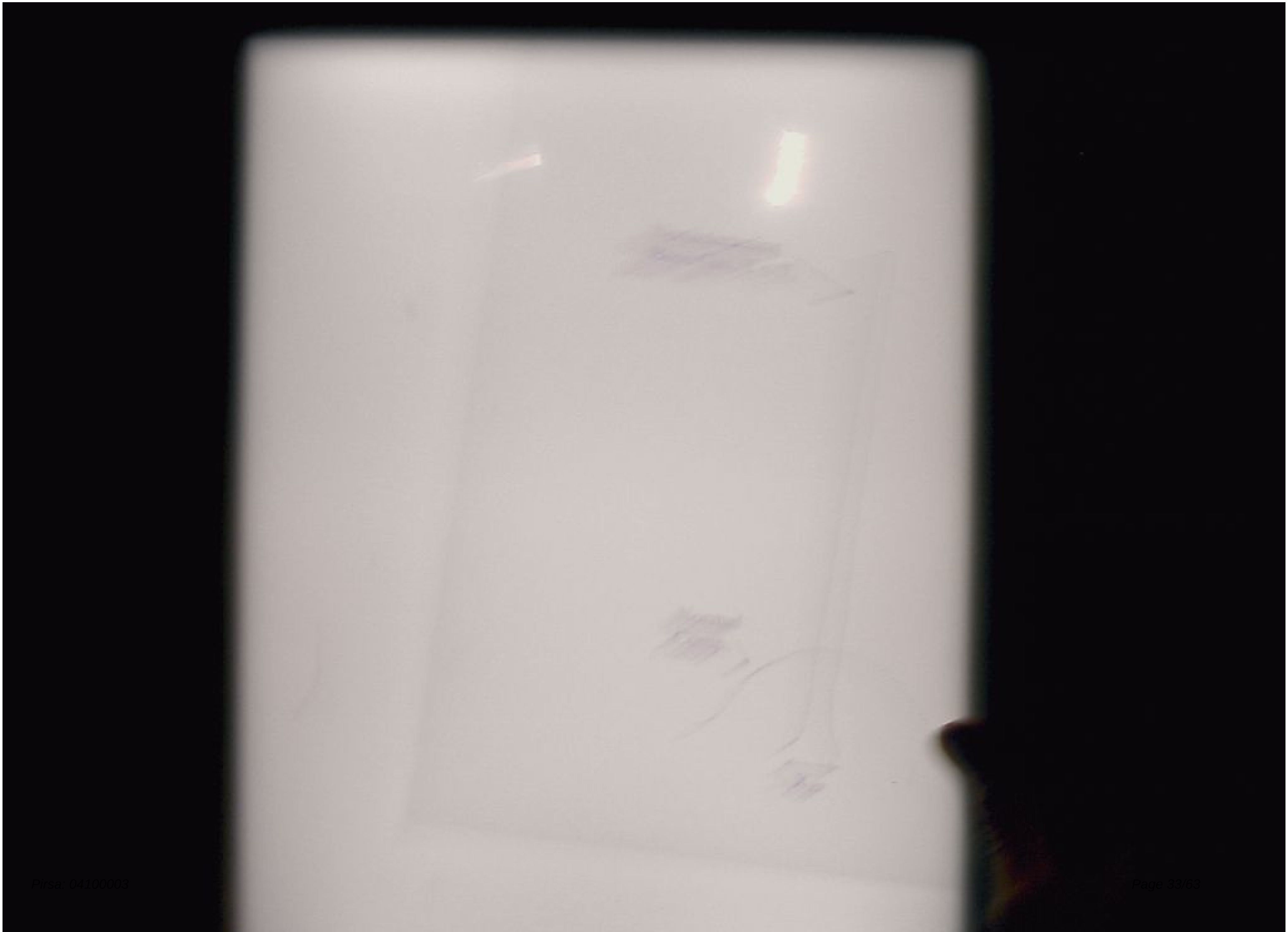
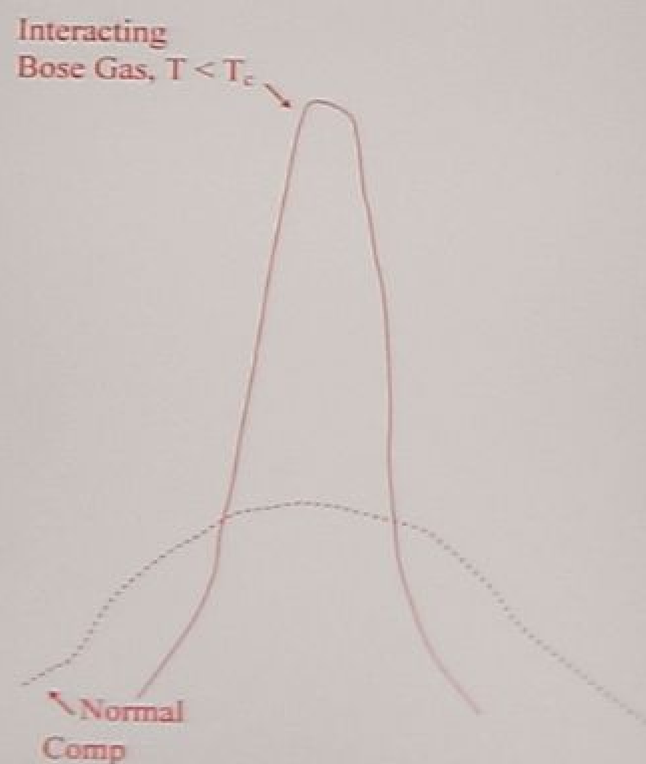



Noninteracting
Bose Gas, T < T_c
Normal
Comp.
~ X_{ZP}

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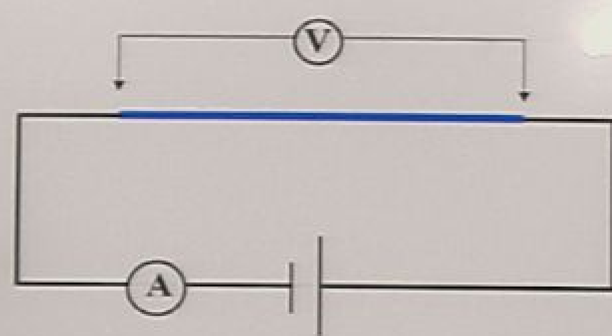
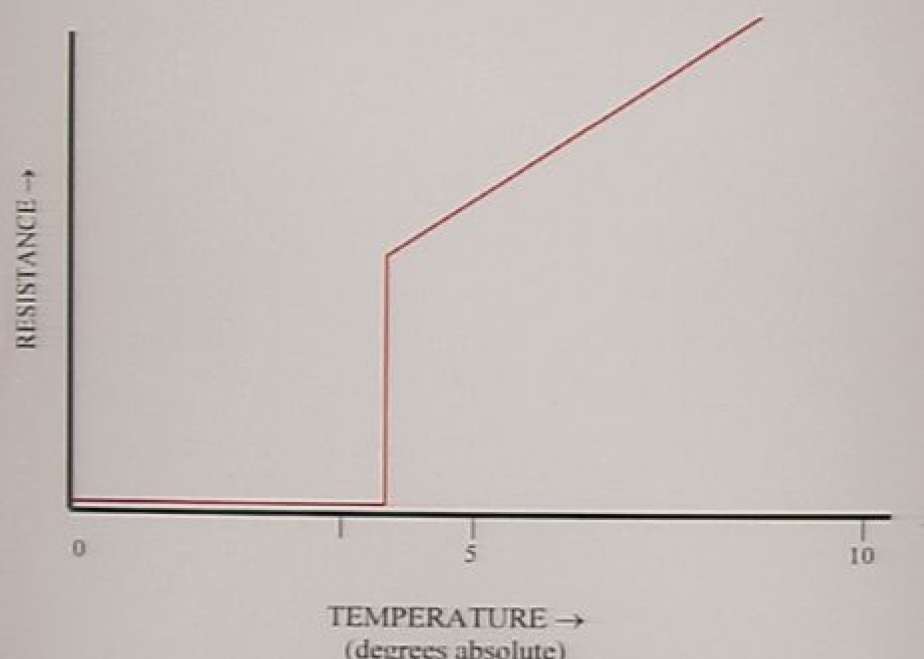
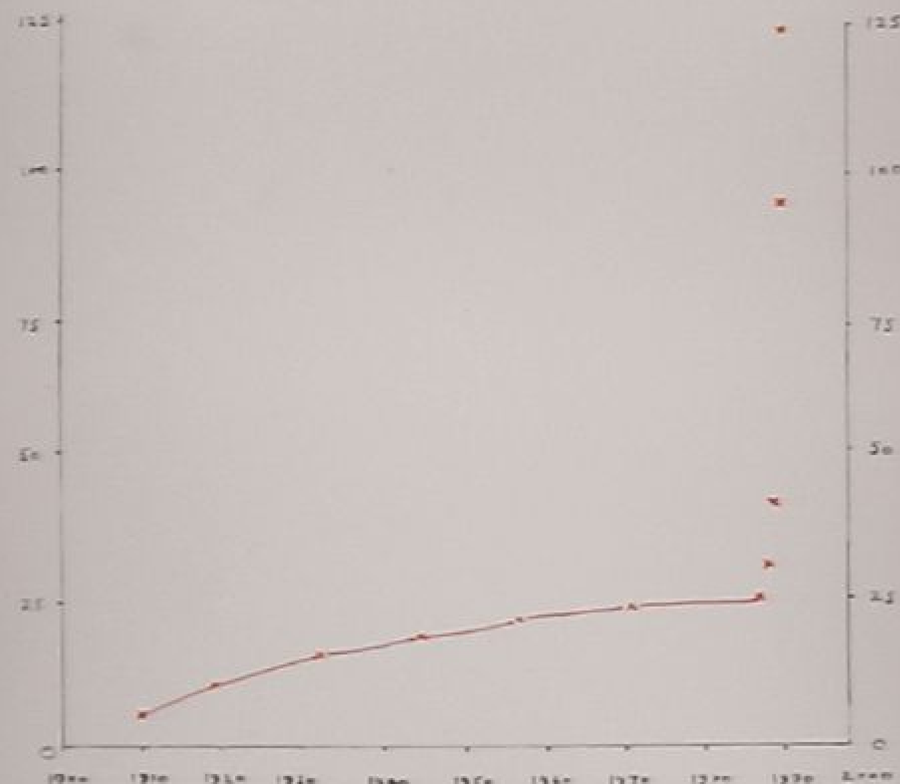


resistance of — = V/A = voltage/current



HISTORY OF THE HIGHEST TEMPERATURE

("T_c") AT WHICH SUPERCONDUCTIVITY KNOWN



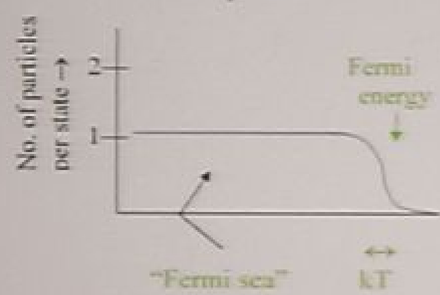
PHYSICS OF SUPERCONDUCTIVITY

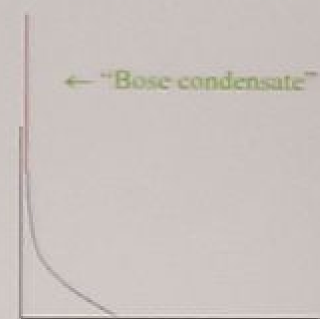
"Spin" of elementary particles $= \frac{n}{2}\hbar$

$0, 1, 2....$ bosons

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

At low temperatures:





Electrons in metals: spin ½ ⇒ fermions

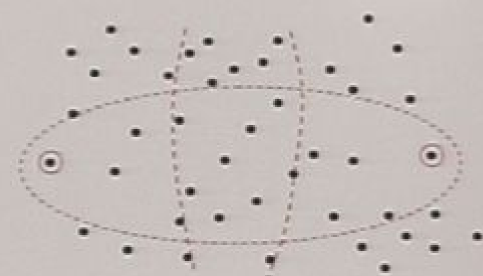
But a compound object consisting of an even no. of fermions has spin 0, 1, 2 ... ⇒ boson.

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

⇒ can undergo Bose condensation

Pairing of electrons:

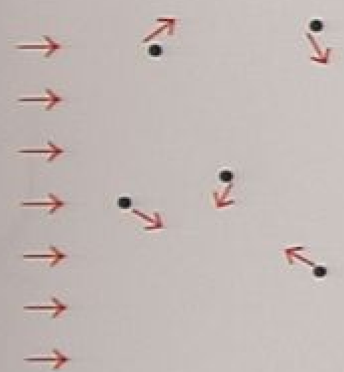
"di-electronic molecules"



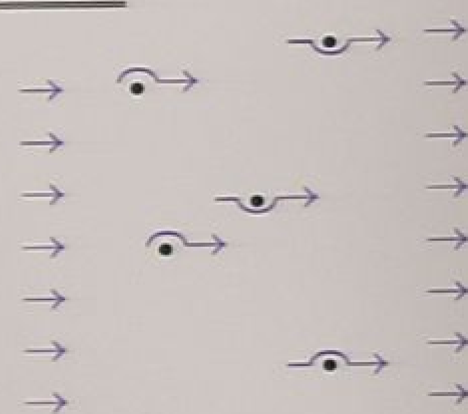
Cooper Pairs

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

$\Rightarrow$ must all do **exactly the same thing at the same time** (also in nonequilibrium situation)

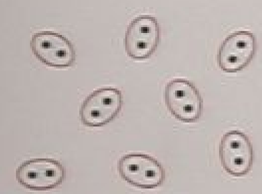


Single electrons in normal metal



Cooper pairs in superconductor

Pairing of electrons:



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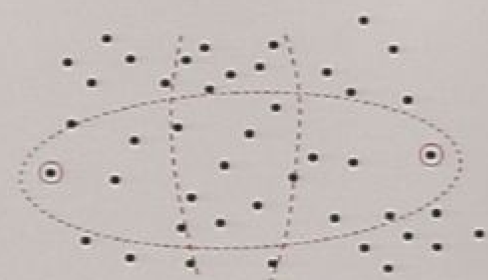

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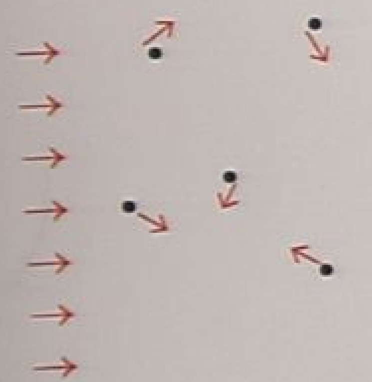

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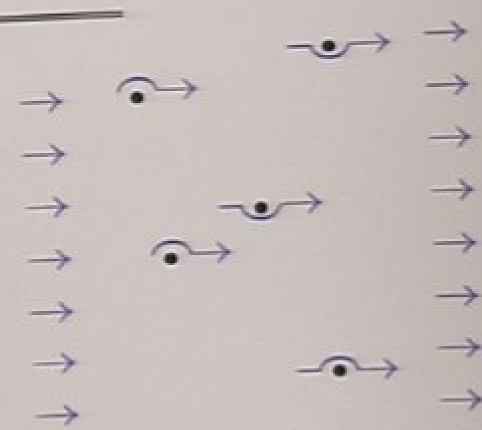
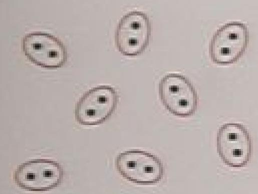
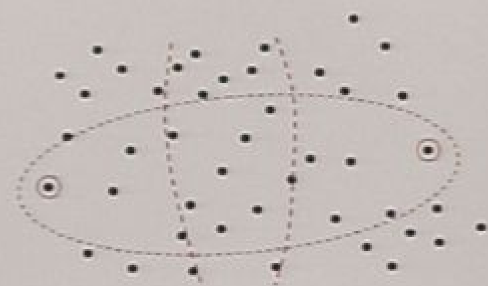


Cooper pairs in superconductor

Pairing of electrons:



"di-electronic molecules"



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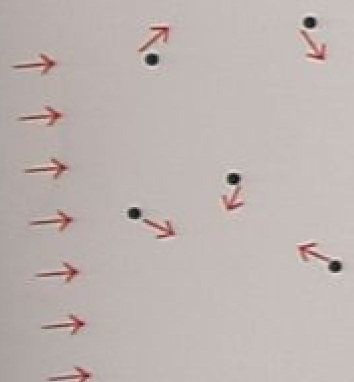

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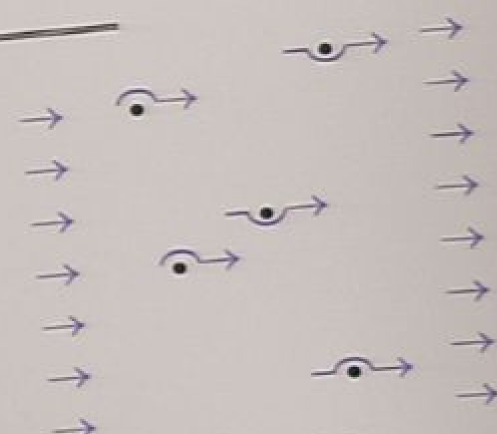
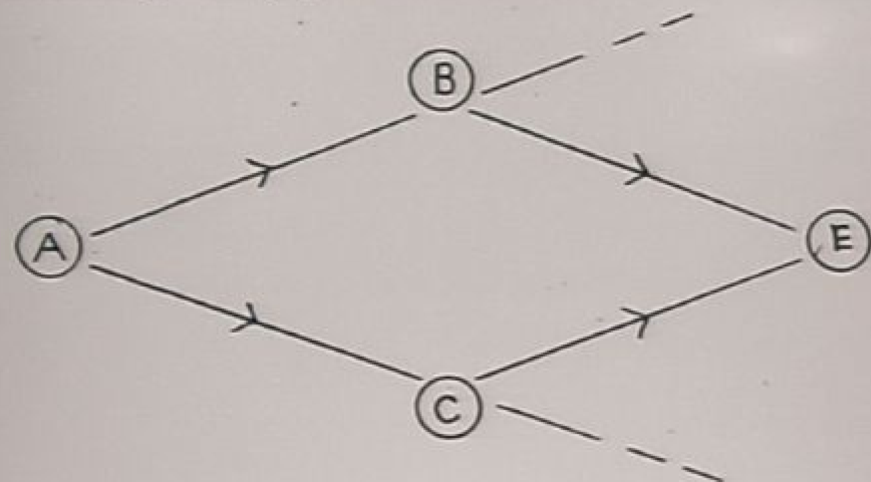


Cooper pairs in superconductor

Account given by quantum mechanics:



Each possible process is represented by a probability amplitude **A** which can be positive or negative.

- Total amplitude to go from A to E = sum of amplitudes

  for possible paths, i.e. A→B →E and/or A→C→E

- Probability to go from A to E = square of total amplitude.

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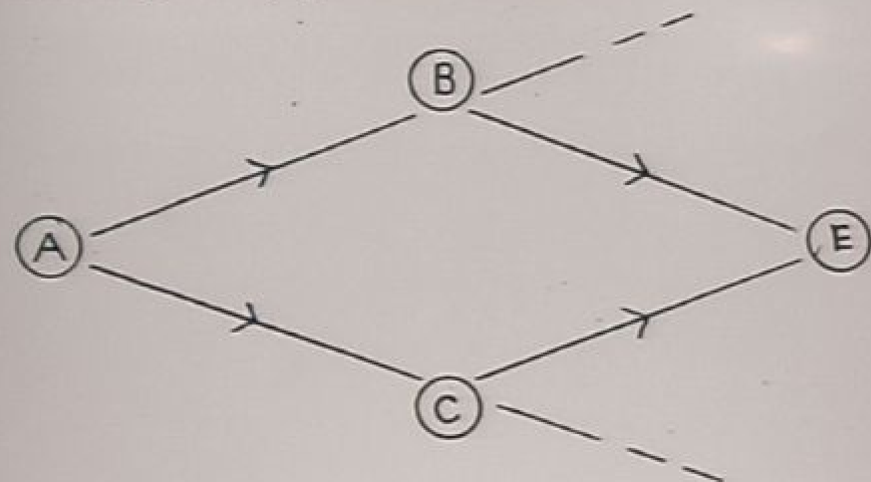

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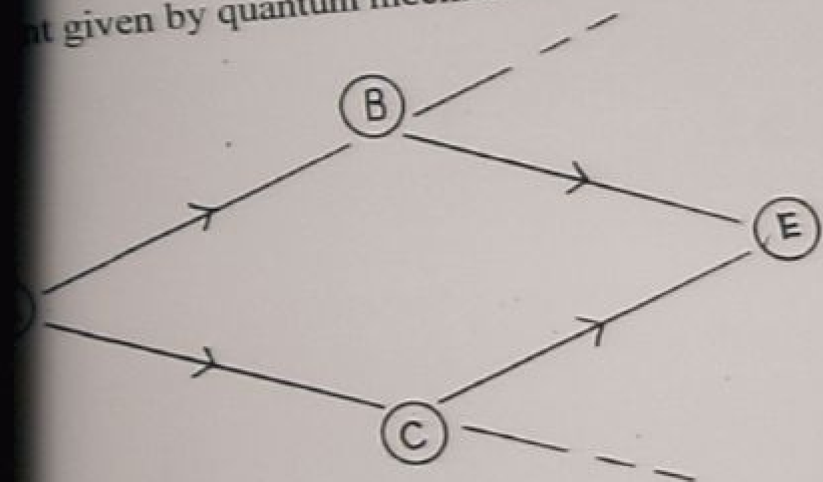

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A to E = square of total amplitude.

1. If C shut off: $A_{tot} = A_B \Rightarrow P = A_B^2 \Leftarrow P_B$

2. If B shut off: $A_{tot} = A_C \Rightarrow P = A_C^2 \Leftarrow P_C$

3. If both paths open:

$A_{tot} = A_B + A_C \leftarrow$ "SUPERPOSITION"

$\Rightarrow P = A_{tot}^2 = (A_B + A_C)^2 = A_B^2 + A_C^2 + 2\, A_B\, A_C$

$= P_B + P_C + 2A_BA_C \leftarrow$ "interference" term

$\Leftarrow P_{B\text{ or }C}$

TO GET INTERFERENCE, A_B AND A_C MUST SIMULTANEOUSLY "EXIST" FOR EACH ATOM

1. If C shut off: $A_{tot} = A_B \Rightarrow P = A_B^2 \Leftarrow P_B$

2. If B shut off: $A_{tot} = A_C \Rightarrow P = A_C^2 \Leftarrow P_C$

3. If both paths open:

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$\Rightarrow P = A_{tot}^2 = (A_B + A_C)^2 = A_B^2 + A_C^2 \quad + 2\, A_B\, A_C$

$= P_B + P_C + 2A_BA_C \leftarrow$ "interference" term

$\Leftarrow P_{B\ or\ C}$

TO GET INTERFERENCE, A_B AND A_C MUST SIMULTANEOUSLY "EXIST" FOR EACH ATOM

Suppose $P_B = P_C$, then $A_B = \pm A_C$.

If $A_B = + A_C$. $\quad P_{B\text{ or }C} = P_B + P_C + 2A_B^2 = 4P_B = 2(P_B + P_C)$

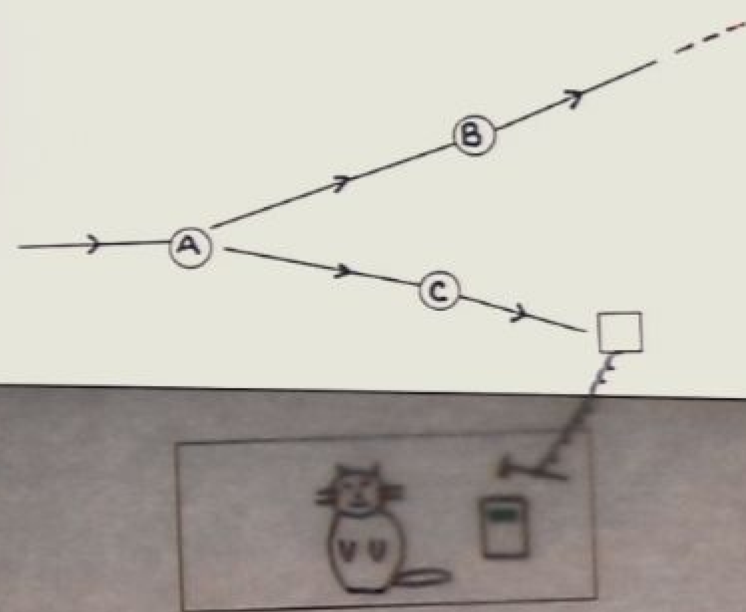
If $A_B = - A_C$. $\quad P_{B\text{ or }C} = P_B + P_C - 2A_B^2 = P_B + P_C - 2P_B = 0$

If $A_B = \pm A_C$. $\quad$ at random

$\bar{P}_{B\text{ or }C} = P_B + P_C$ ← "COMMON SENSE" RESULT

WHEN A_B AND A_C SIMULTANEOUSLY "EXIST",
NEITHER B NOR C "SELECTED".

CAS 7 (4)



In quantum mechanics, if state 1 → state 1' and state 2 → 2', then <u>superposition</u> of 1 and 2 → superposition of 1' and 2'

Here: B → cat alive

C → cat dead

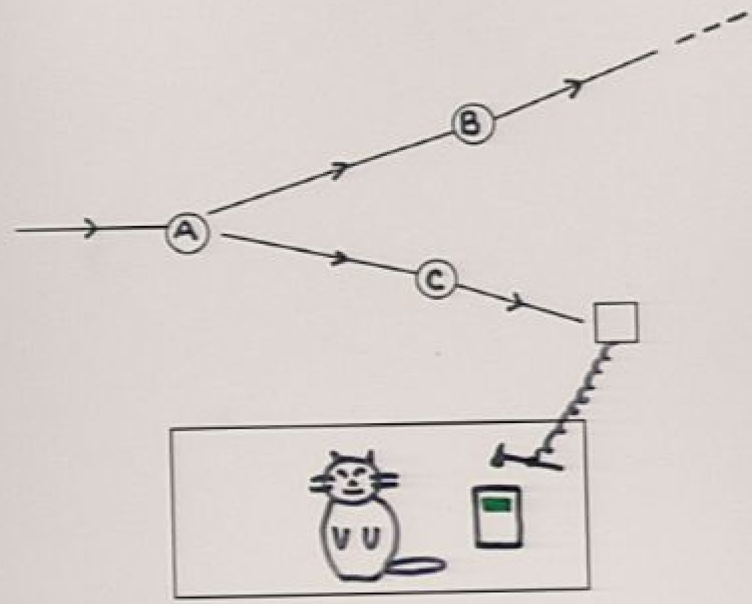
∴ superposition of B and C → <u>superposition of "alive and "dead"</u>

i.e.

ampl. (cat alive) ≠ 0

ampl. (cat dead) ≠ 0

CAS 7 ⊕



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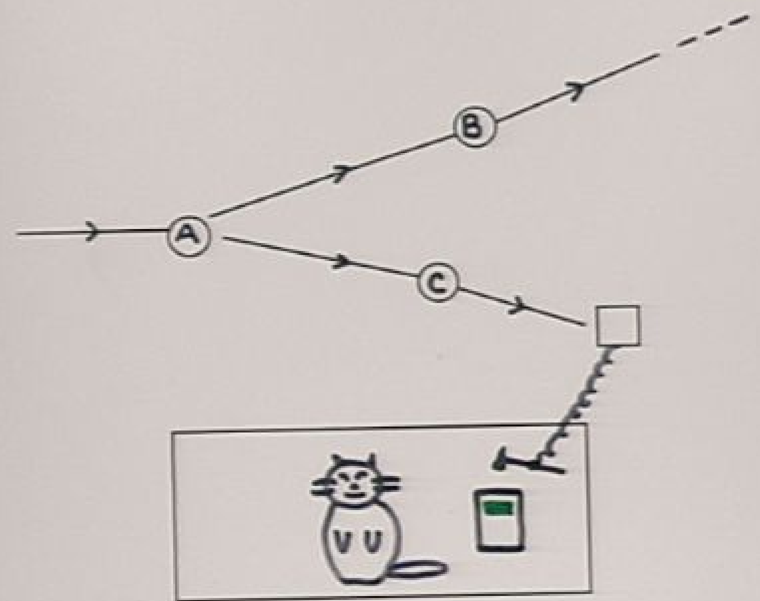
Here, B → cat alive

C → cat dead

∴ superposition of B and C → <u>superposition of "alive and "dead"</u>!

i.e.

$$\begin{cases} \text{ampl. (cat alive)} \neq 0 \\ \text{ampl. (cat dead)} \neq 0 \end{cases}$$



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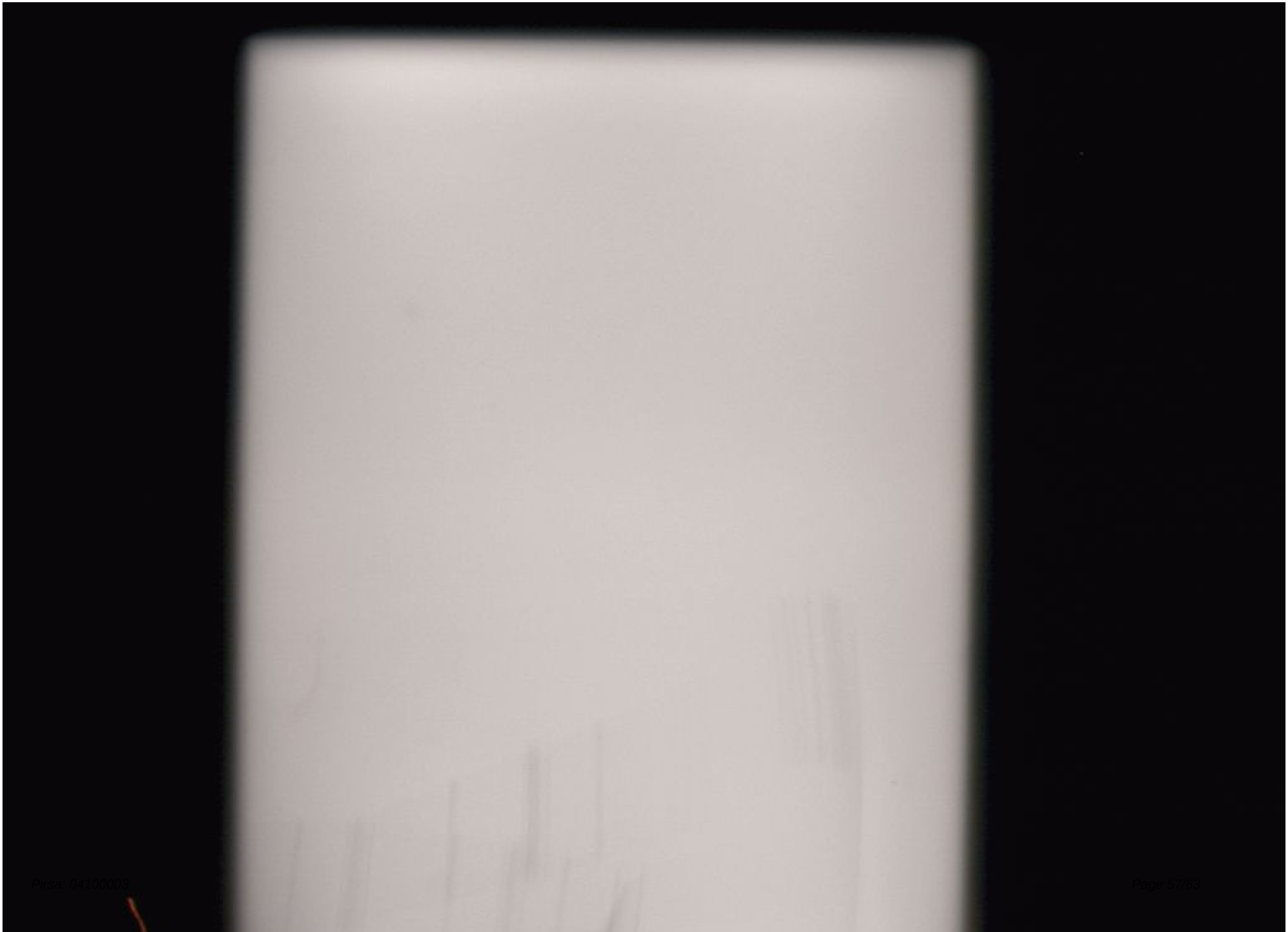
∴ superposition of B and C → <u>superposition of "alive and "dead"!</u>

i.e.

$$\begin{cases} \text{ampl. (cat alive)} \neq 0 \\ \text{ampl. (cat dead)} \neq 0 \end{cases}$$



Some "resolutions" of the Cat paradox

(a) Assume quantum mechanics is universal

(i) Orthodox" resolution

Recall:

$P_{B \text{ or } C} = P_B + P_C + 2A_B A_C$ ← "interference" term

If $A_C = \pm A_B$ at random,

averages to zero

$$P_{B \text{ or } C} = P_B + P_C + \overline{2A_B A_C} = P_B + P_C$$

Effect of "outside world" is, generally speaking, to randomize sign; more effective as system gets larger.

=> interference term vanishes for "everyday" objects (cats!) ("decoherence")

=> each system chooses either B or C?

(ii) extreme statistical

(iii) "many-worlds"

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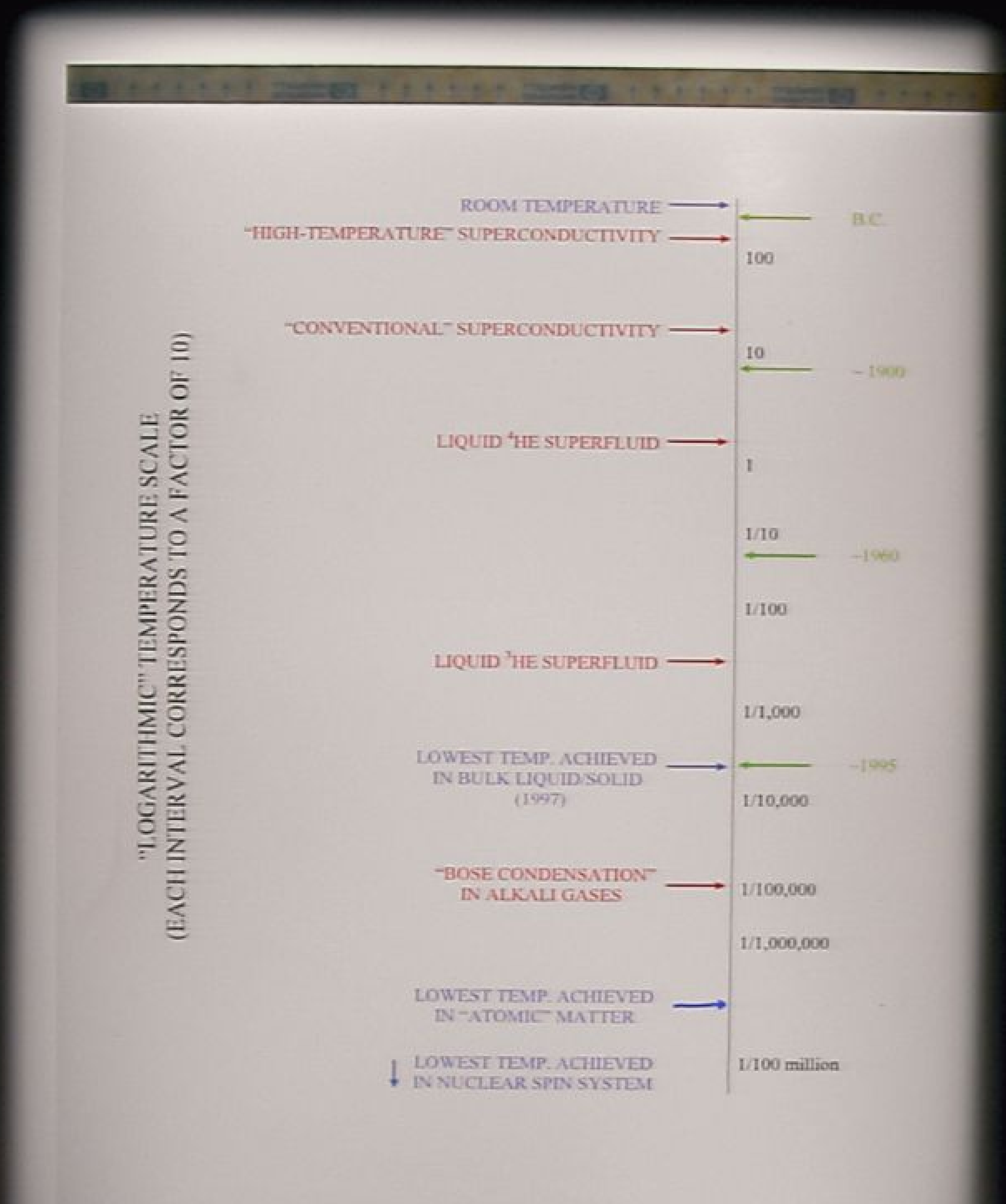
"LOGARITHMIC" TEMPERATURE SCALE
(EACH INTERVAL CORRESPONDS TO A FACTOR OF 10)
ROOM TEMPERATURE
"HIGH-TEMPERATURE" SUPERCONDUCTIVITY
B.C.
100
"CONVENTIONAL" SUPERCONDUCTIVITY
10
~1900
LIQUID ^{4}HE SUPERFLUID
1
1/10
~1960
1/100
LIQUID ^{3}HE SUPERFLUID
1/1,000
LOWEST TEMP. ACHIEVED
IN BULK LIQUID/SOLID
(1997)
~1995
1/10,000
"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

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