

Title: Quantum Mechanics 6 - The Strong and Weak Interpretations of Heisenberg Uncertainty Principle

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URL: <http://pirsa.org/08080081>

Abstract: A more in depth discussion of what the Heisenberg Uncertainty Principle is trying to tell us about the nature of reality.

Learning Outcomes:

• Understanding the strong interpretation of the HUP: Particles cannot simultaneously possess a definite position and a definite momentum. •

• Why the classical question: Given a particle's initial position and momentum, what is its position and momentum as some later time t ? • makes no sense in the quantum world.

• Richard Feynman's remarkable sum over paths interpretation of quantum mechanics.

"Strong" Interpretation of HUP

"Strang" Interpretation of HUP

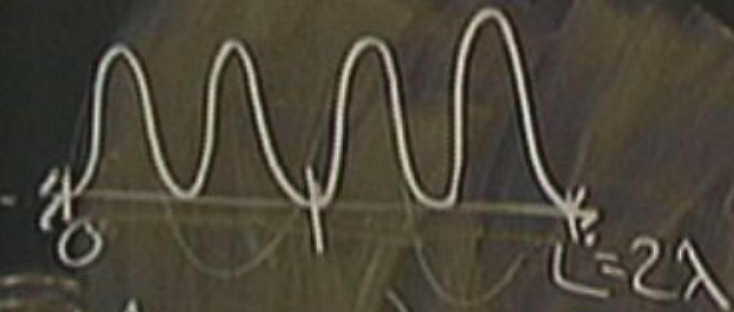
Particle cannot simultaneously possess
a definite position and momentum

"Strong" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum



P₃



$$\Delta x = \lambda$$

$$p = \frac{h}{\lambda}$$

$$\Delta p = \frac{h}{\lambda}$$

$$\Delta x \Delta p = h$$

general.

$$\Delta x \Delta p \geq \frac{h}{4\pi} \quad \text{HUP}$$

$$\lambda p = h \quad \text{de Broglie}$$

"Strong" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum

$$\uparrow$$
$$\Delta x = 0$$

"Strong" Interpretation of HUP

Particle cannot simultaneously possess
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"Strong" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum

$$\uparrow$$
$$\Delta x = 0$$

$$\uparrow$$
$$\Delta p = 0$$

general. $\Delta p \geq \frac{h}{4\pi \Delta x}$

$$\Delta x \Delta p \geq \frac{h}{4\pi} \quad \text{HUP}$$

* $L = 2\lambda$

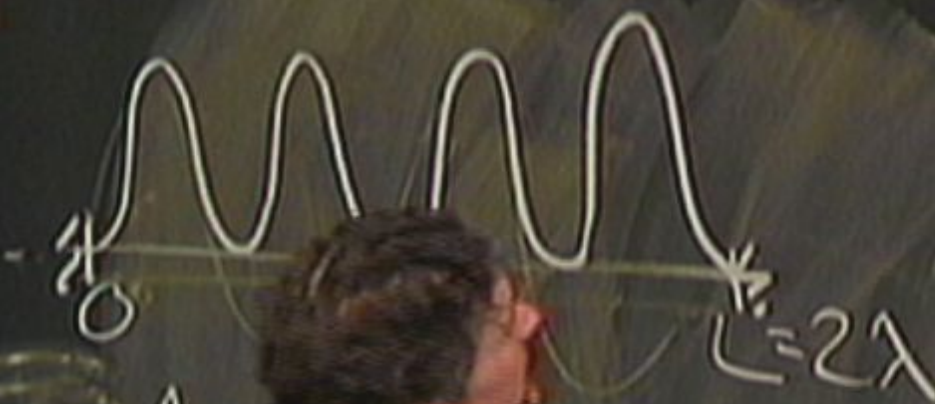
$\Delta x \Delta p = h$ $\lambda p = h$ de Broglie

"Strang"
Particl
a defir

P_3

$$\left(\frac{1}{\lambda}\right) \times (\lambda) = 1$$

general



Δx

$$p = \frac{h}{\lambda}$$

$$\Delta x \Delta p = h$$

||

$$\Delta x \Delta p \geq h$$

$$\lambda p = h$$

"Strong" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum

$$\uparrow$$
$$\Delta x = 0$$

$$E = \frac{p^2}{2m}$$

Δ

"Strong" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum

$$\uparrow$$
$$\Delta x = 0$$

$$\uparrow$$
$$\Delta p = 0$$

$$E = \frac{p^2}{2m}$$

$$p = mv$$

$$E^2 = m^2 c^4 + p^2 c^2$$

"Strong" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum

$$\uparrow$$
$$\Delta x = 0$$

$$\uparrow$$
$$\Delta p = 0$$

$$E = \frac{p^2}{2m}$$

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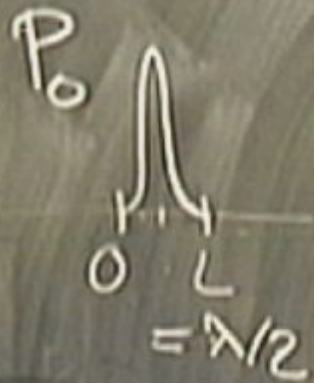
$$E^2 = m^2 c^4 + p^2 c^2$$

$$\rightarrow E \approx mc^2 + \frac{p^2}{2m}$$

"Strang" Interpretation of HUP

Particle cannot simultaneously possess
a definite position and momentum

$$\begin{array}{ccc} \uparrow & & \uparrow \\ \Delta x = 0 & & \Delta p = 0 \\ \textcircled{E = \frac{p^2}{2m}} \quad p = mv & \textcircled{E^2 = m^2 c^4 + p^2 c^2} & \rightarrow E \approx \textcircled{mc^2} + \frac{p^2}{2m} \\ \downarrow & & \downarrow \end{array}$$

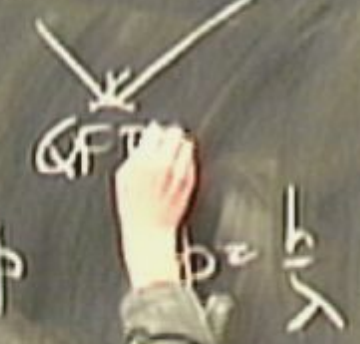


$$\Delta x = \frac{\lambda}{2} \text{ smaller}$$



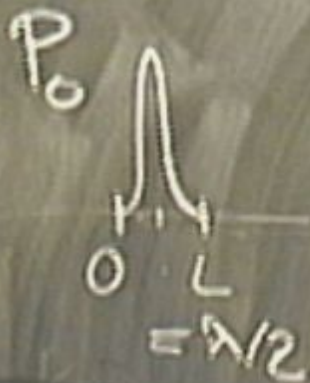
$$\Delta x = \frac{h}{\Delta p}$$

QM SR



"rephobic"

Same



$-\frac{h}{\lambda}$

0

$+\frac{h}{\lambda}$

QM

SR

QFT

p

$p = \frac{h}{\lambda}$

$\Delta x = \frac{\lambda}{4}$ smaller

$\Delta p = \frac{h}{\lambda}$ larger

"claustrophobic"

$\Delta x \Delta p = \frac{h}{4}$ same

classical

classical

Typical.

given $x(0), p(0)$, what is $x(t), p(t)$?

classical

Typical

given $x(0), p(0)$, what is $x(t), p(t)$?

$x(0)$
 $p(0)$



$$F = ma$$

classical

Typical.

given $x(0), p(0)$, what is $x(t), p(t)$?

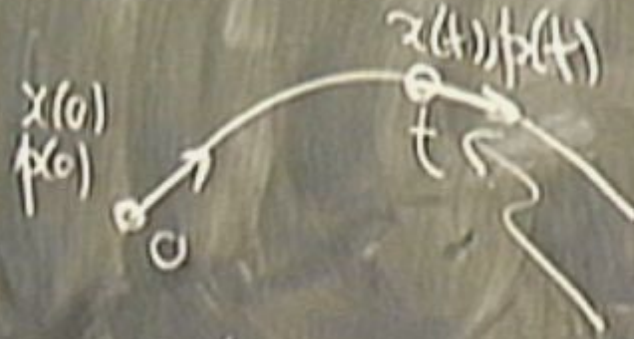


$$F = ma$$

classical

Typical

given $x(0), p(0)$, what is $x(t), p(t)$?

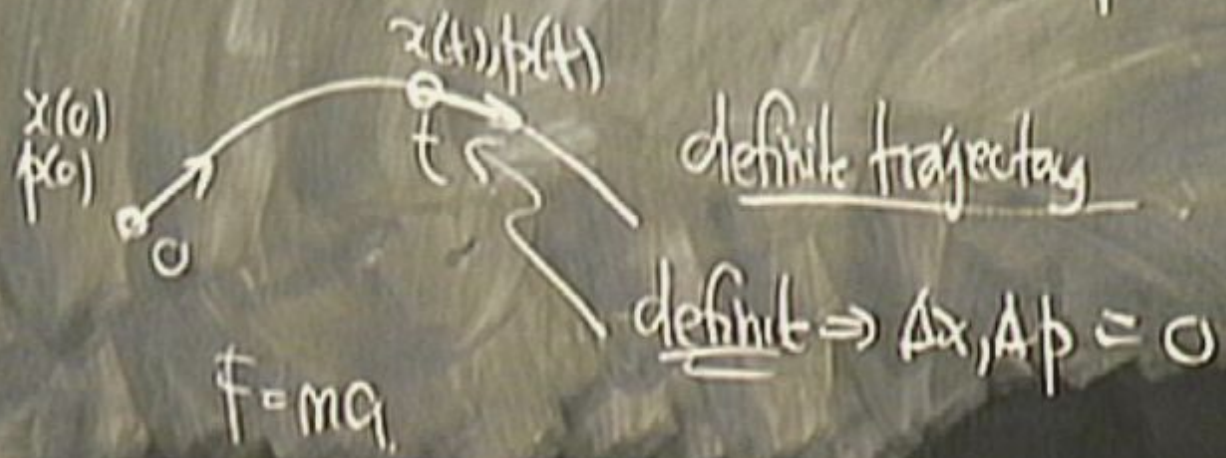


$$F = ma$$

classical

Typical

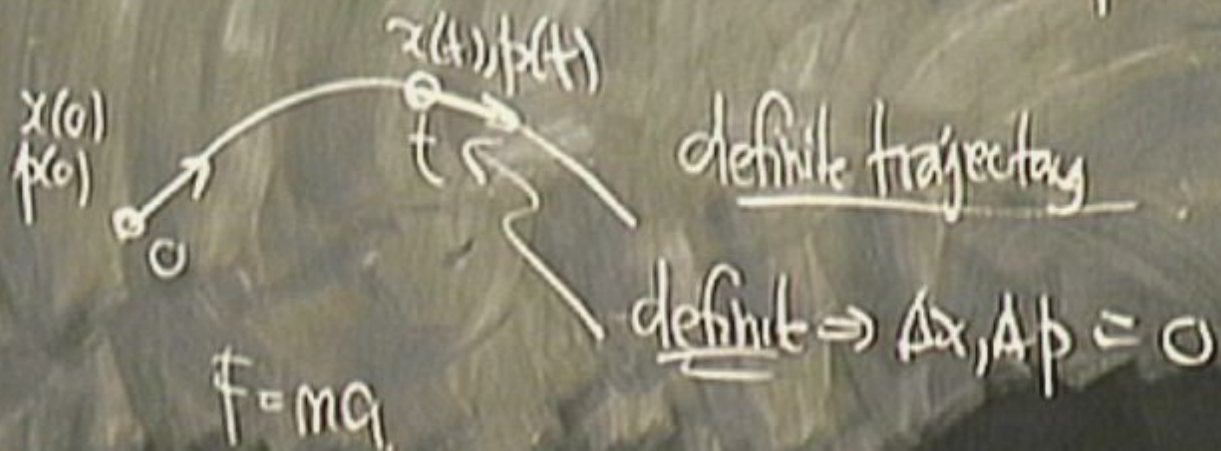
given $x(0), p(0)$, what is $x(t), p(t)$?



classical

Typical question

given $x(0), p(0)$, what is $x(t), p(t)$?



quantum

Typical Question

given $\psi(0)$

quantum

Typical Question

given $\psi(0)$, what is probability

quantum

Typical Question

given $\psi(0)$, what is probability of finding $x(t)$?

quantum

Typical Question

not both

{ given $x(0)$, what is probability of finding $x(t)$ }
{ OR " $p(0)$, " " " " " " $p(t)$ }

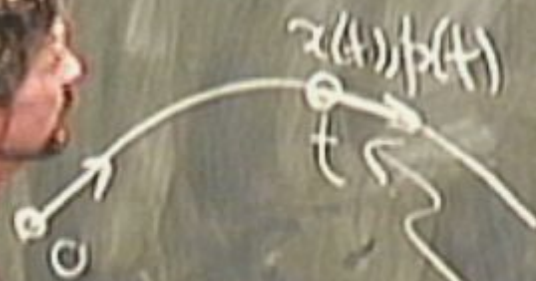
classical

Typical question

$$\underline{x(0)}$$

$$x(t)$$

given $x(0), p(0)$, what is $x(t), p(t)$?



definite trajectory

definit $\Rightarrow \Delta x, \Delta p = 0$

$$F = ma$$

classical

Typical question

$x(0)$

||

||

$x(t)$

given $x(0), p(0)$, what is $x(t), p(t)$?



definite trajectory

definit $\Rightarrow \Delta x, \Delta p = 0$

$F = ma$

quantum

Typical Question

not both

{ given $x(0)$, what is probability of finding $x(t)$
{ OR " $p(0)$, " " " " " $p(t)$ }

use $\lambda = h/p$ to calculate probability

quantum

Typical Question

not both

(given $x(0)$, what is probability of finding $x(t)$)
OR " $p(0)$, " " " " " $p(t)$

use $\lambda = h/p$ to calculate probability

no such thing as a definite trajectory.

$$\left(\frac{h}{\lambda}\right) \times (x) = p$$

general.

$$\Delta p \approx \frac{h}{4\pi \Delta x}$$

quantum

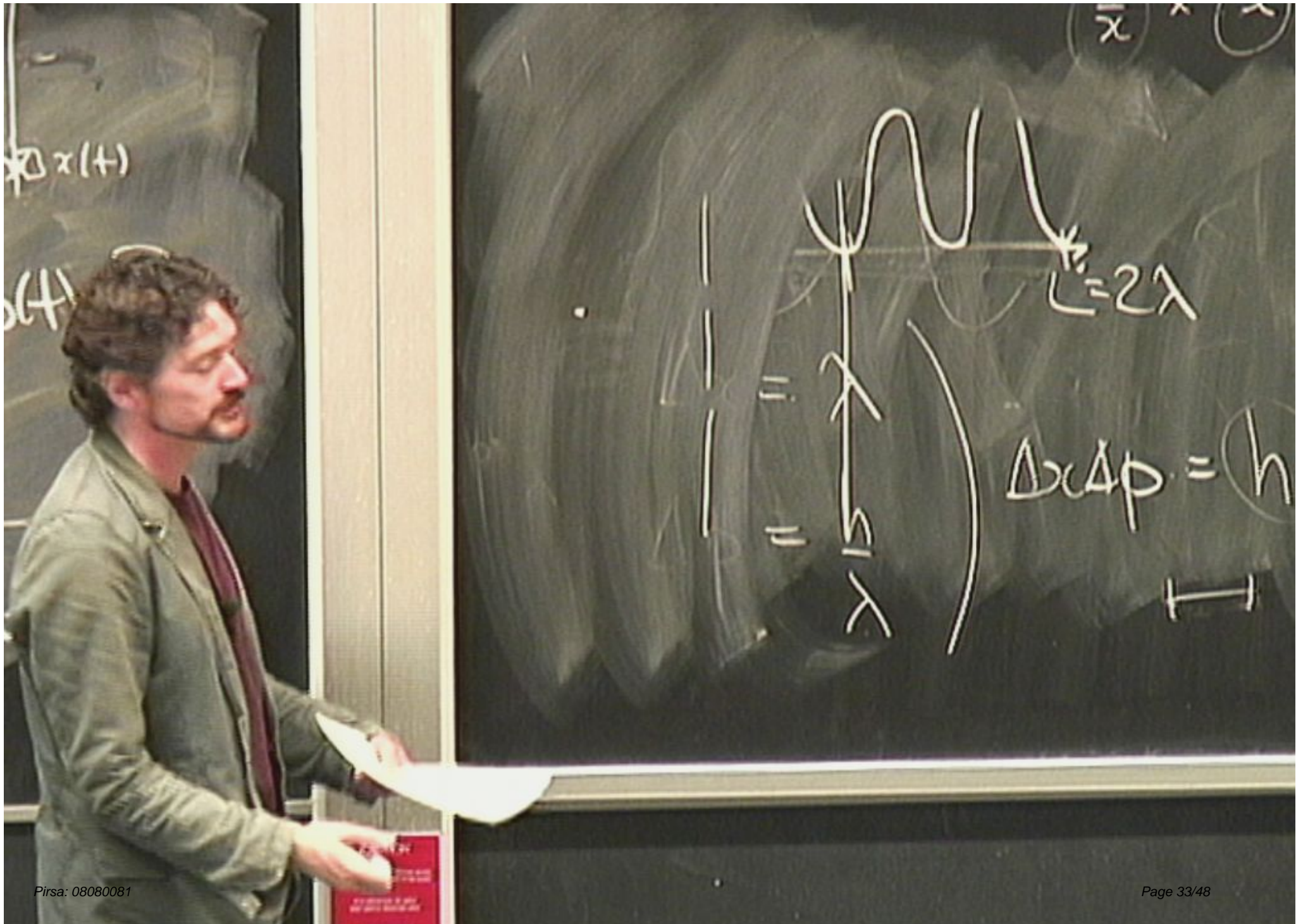
Typical Question

not both

(given $x(0)$, what is probability of finding $x(t)$)
{ OR " $p(0)$, " " " " " $p(t)$ }

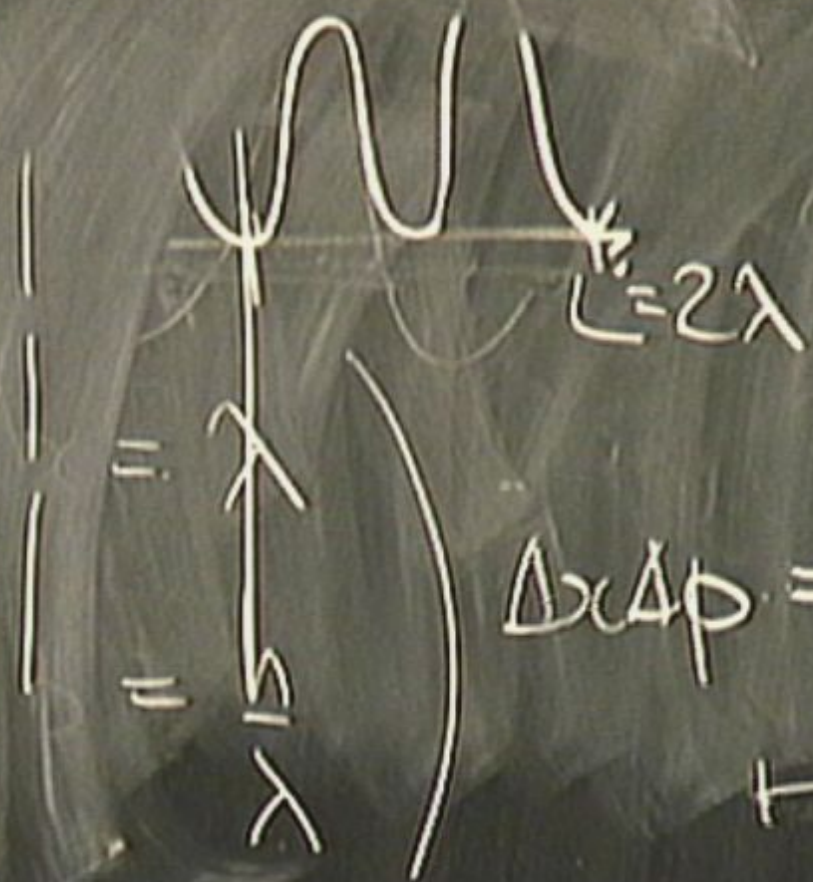
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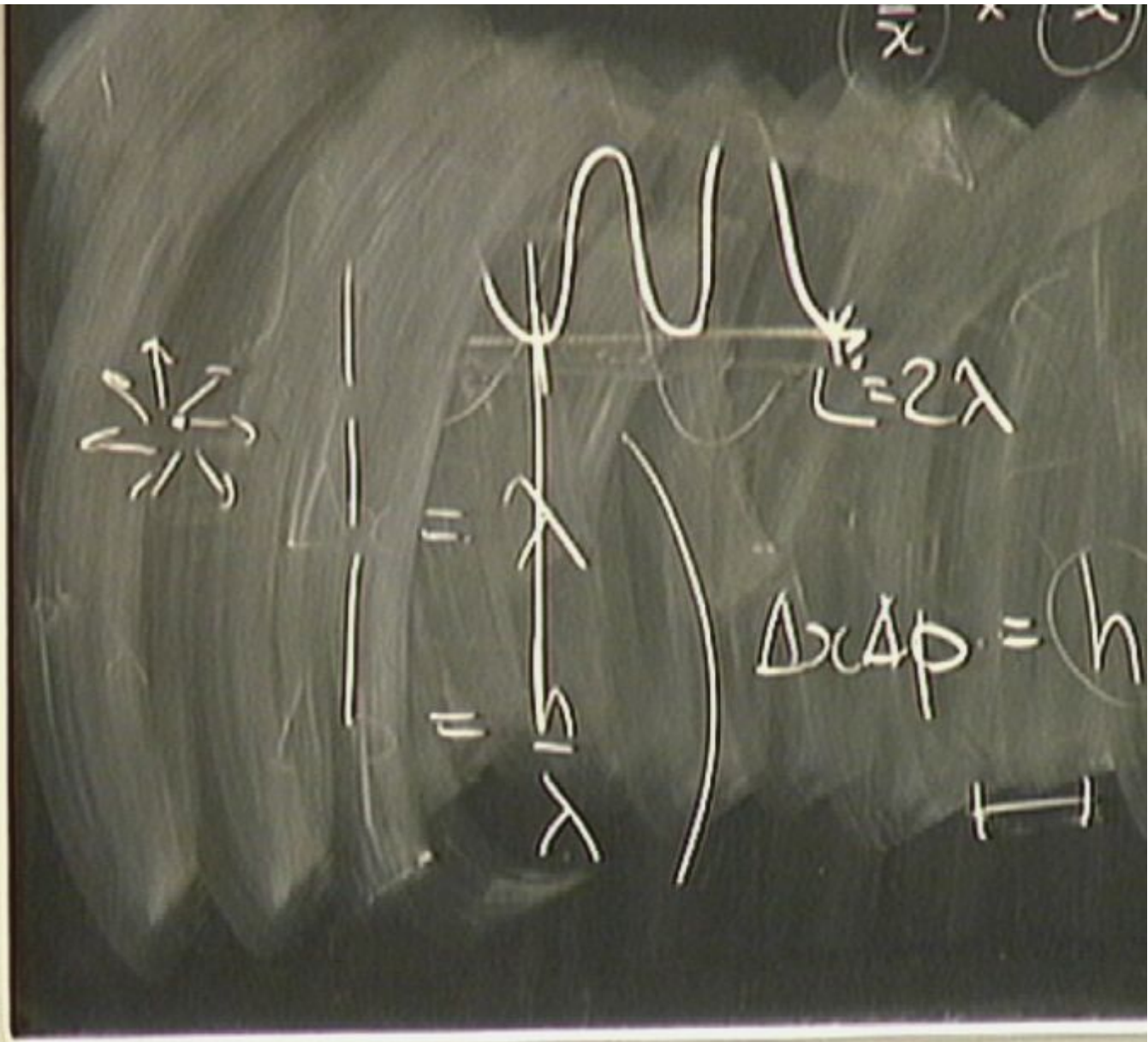
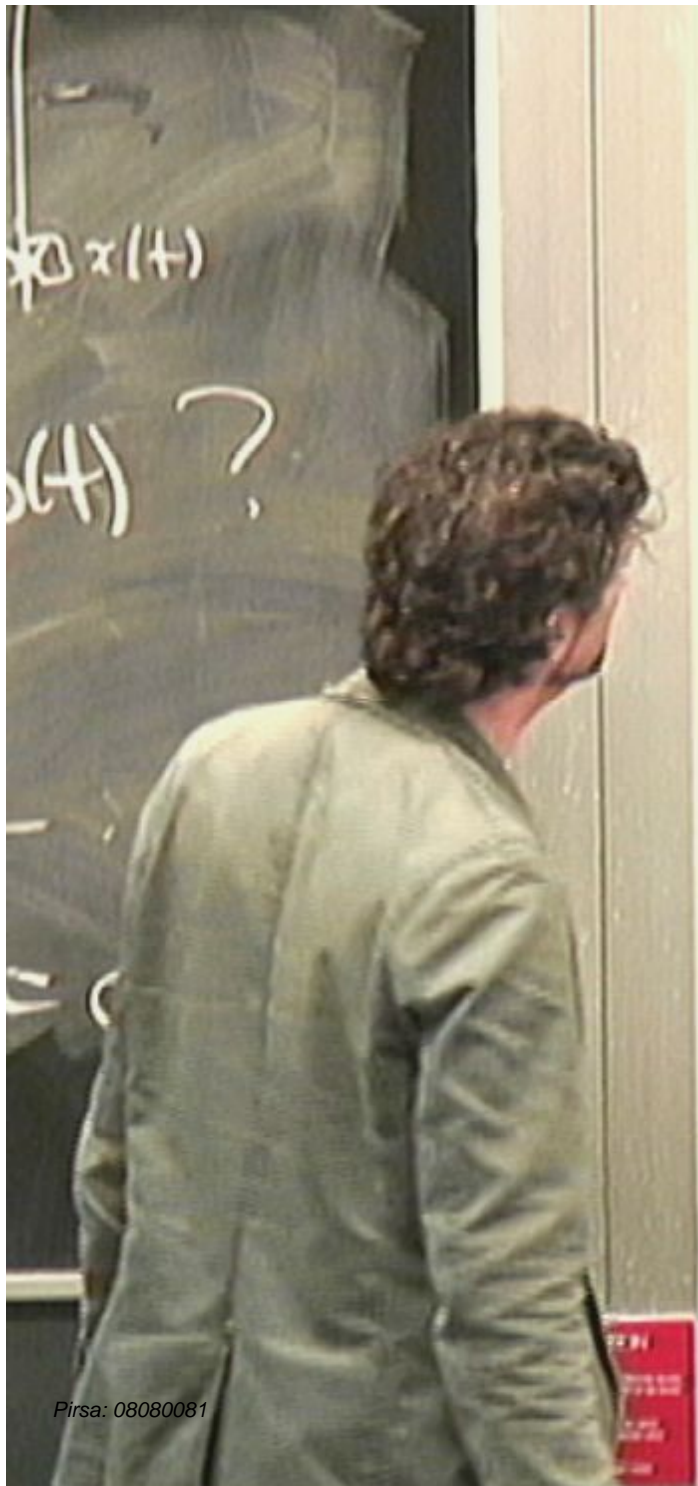


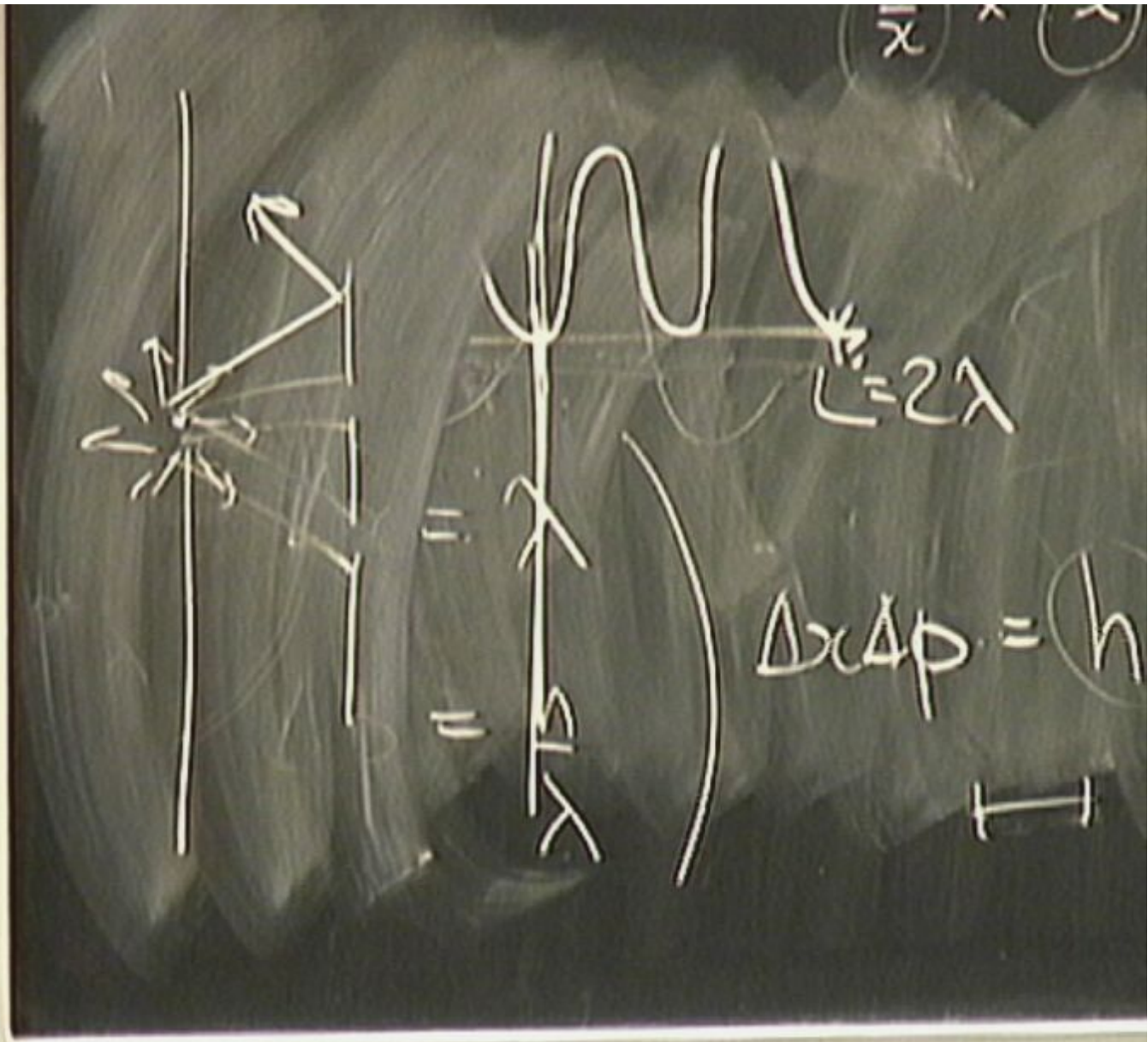
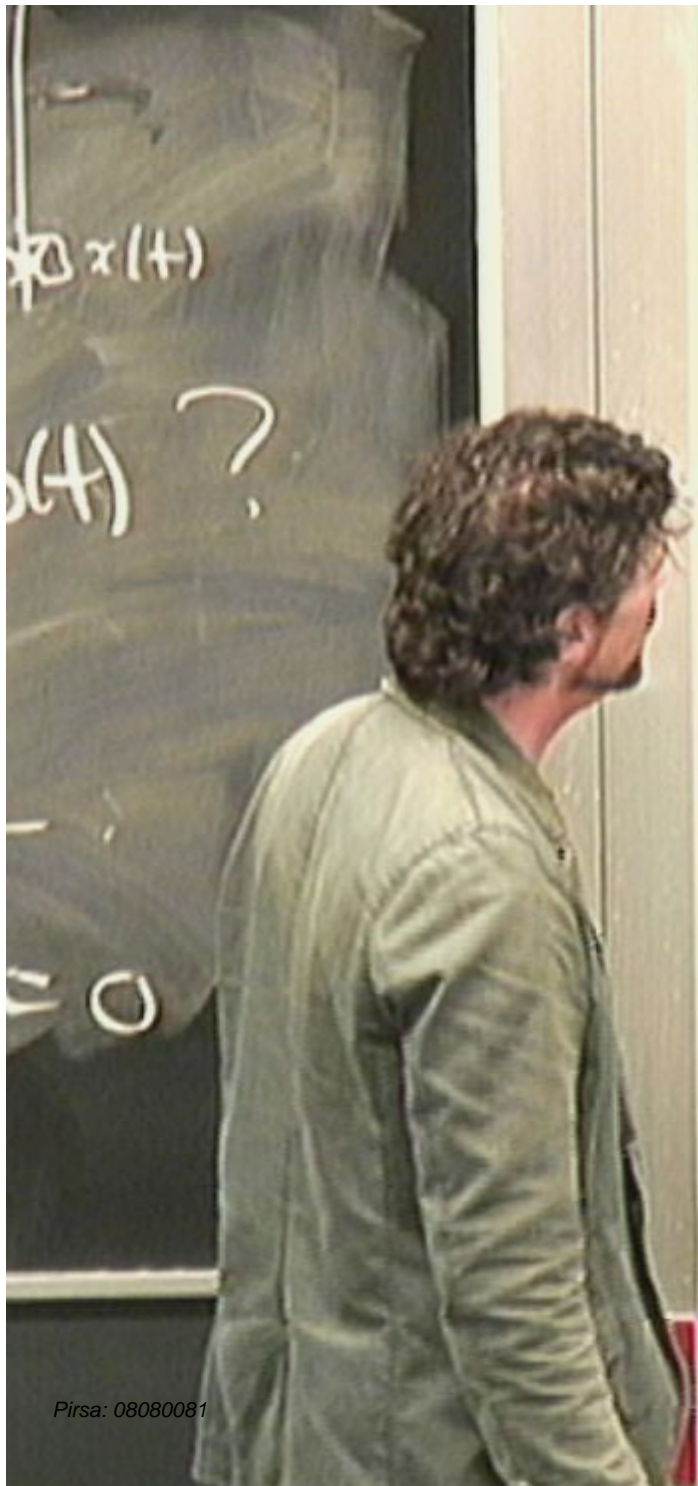
$$x(t)$$

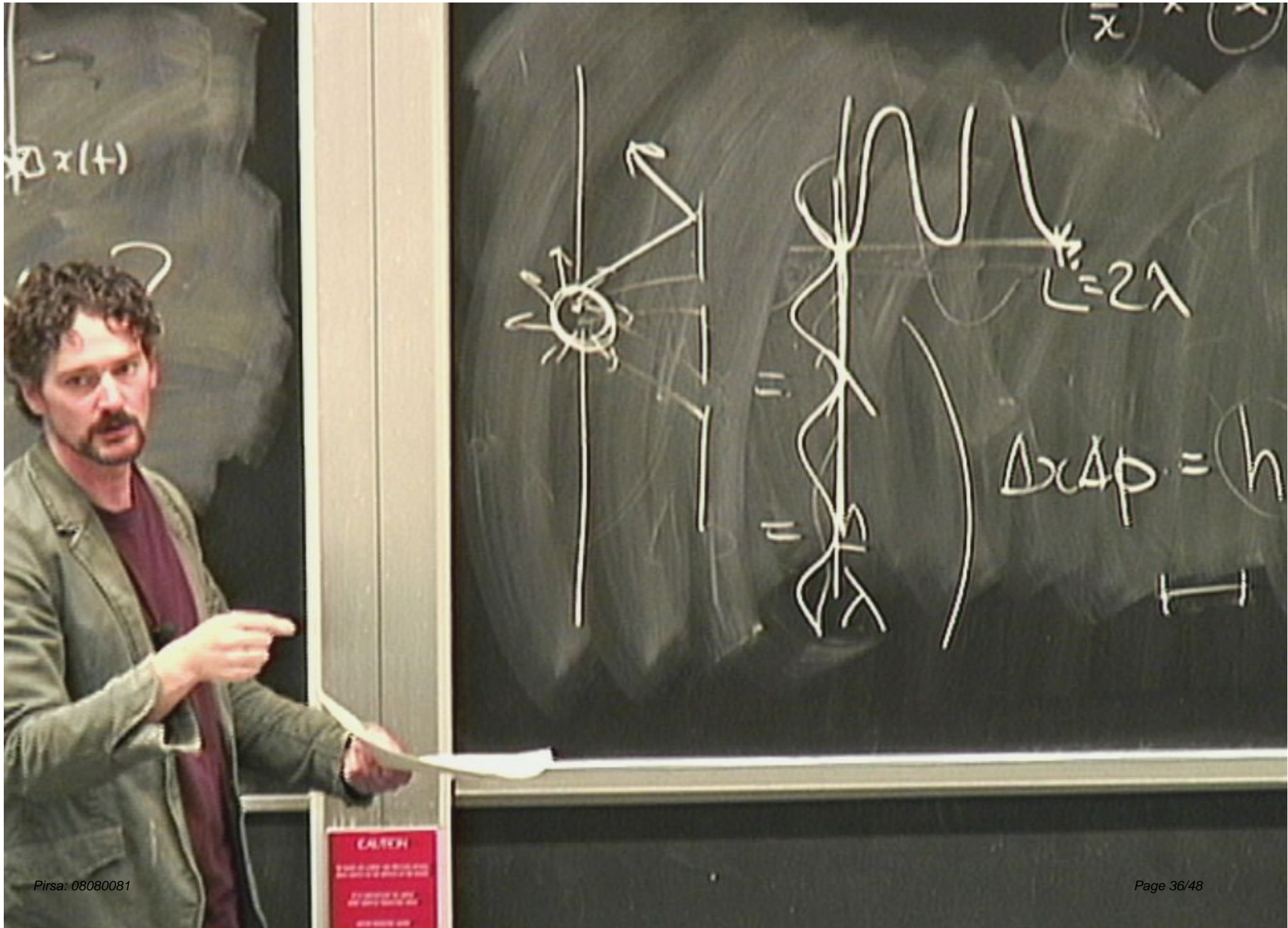
$$x(t)$$

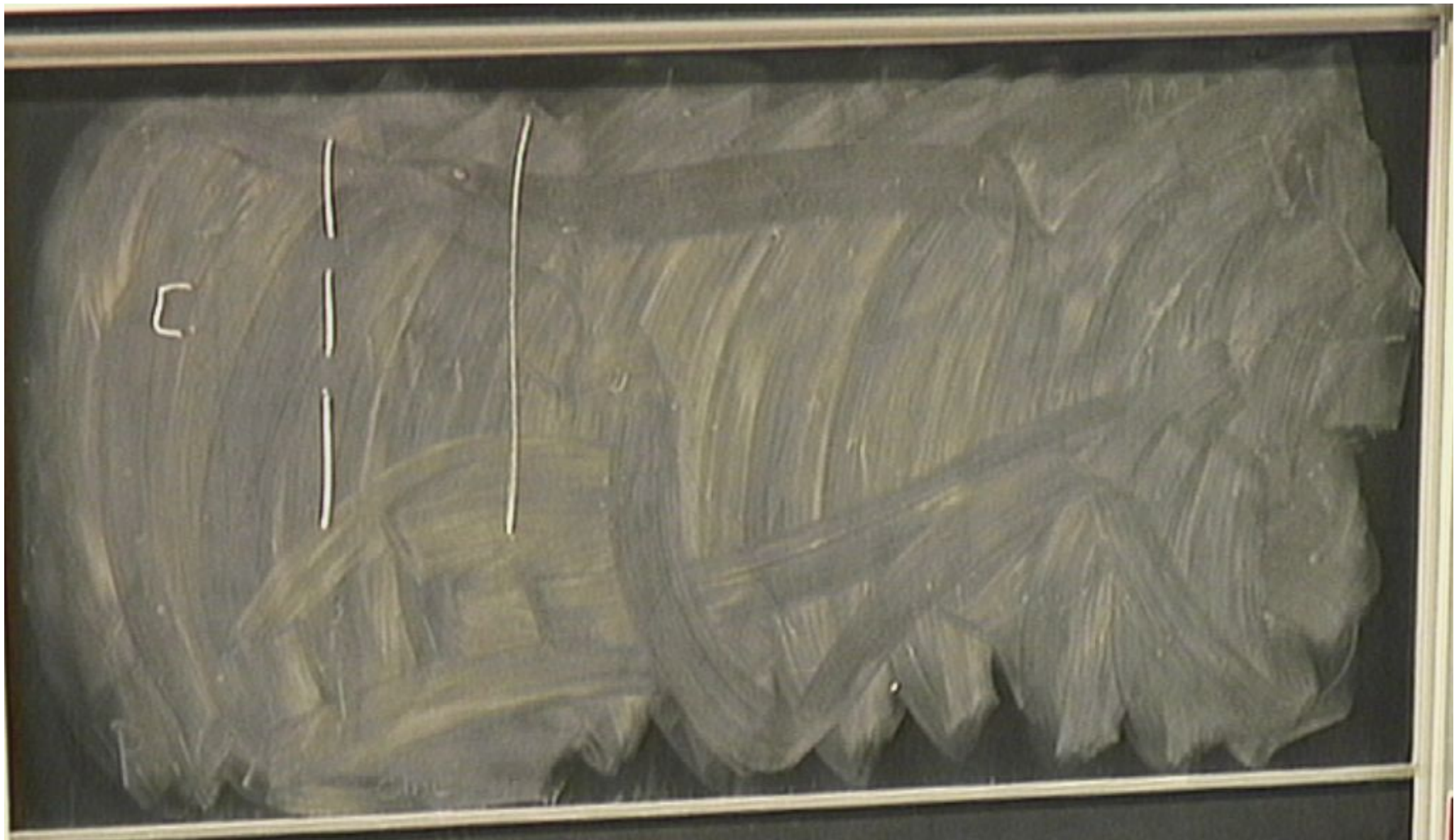


$$\Delta x \Delta p = h$$







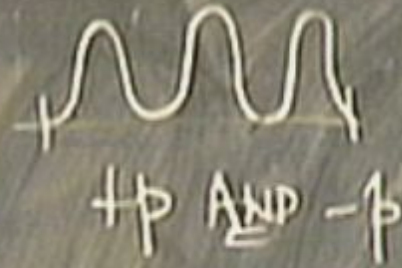
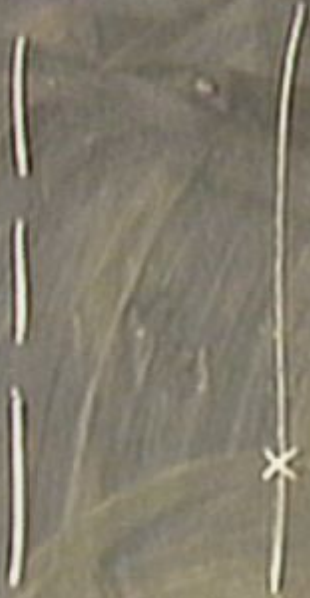


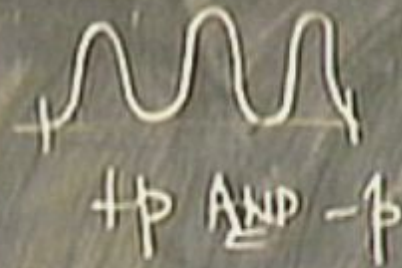
C



$\frac{1}{2} \text{ AND } -\frac{1}{2}$

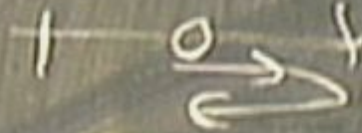
C

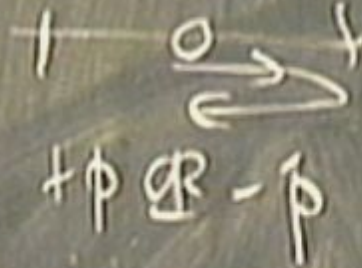
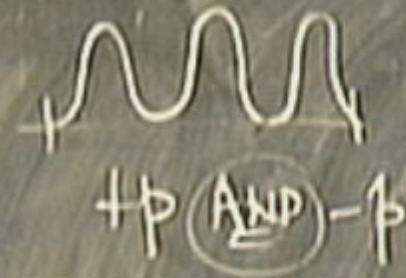


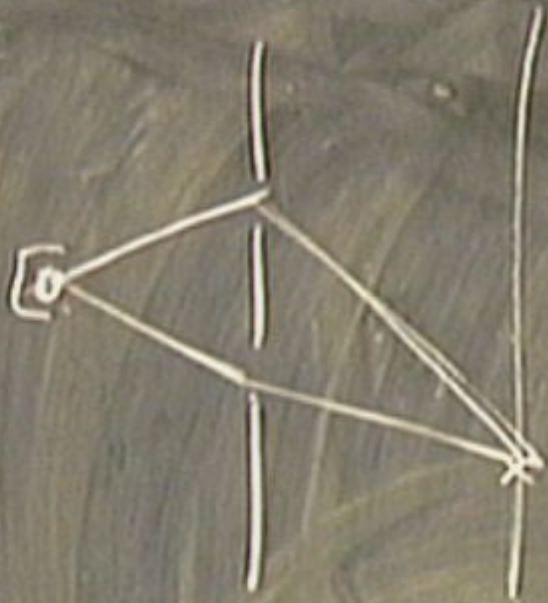




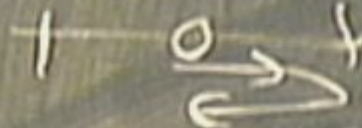
$\pm \text{ AND } - \pm$



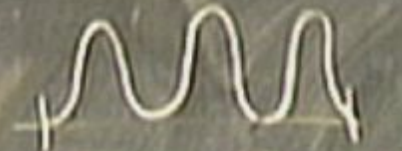
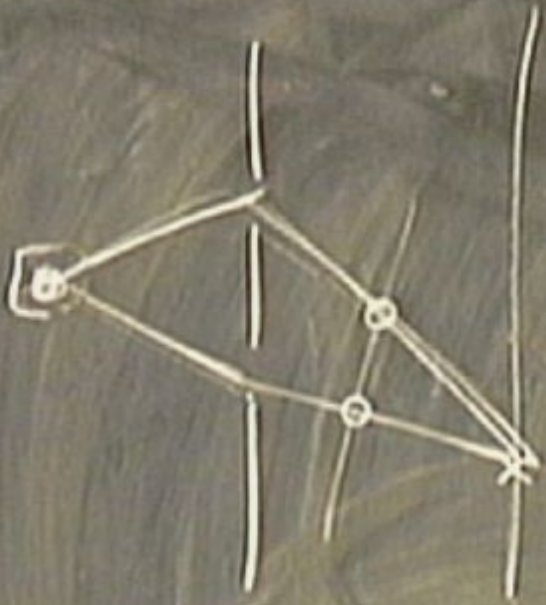




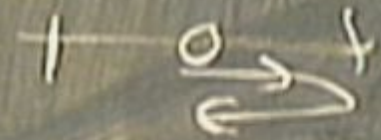
$+p \text{ (AND) } -p$



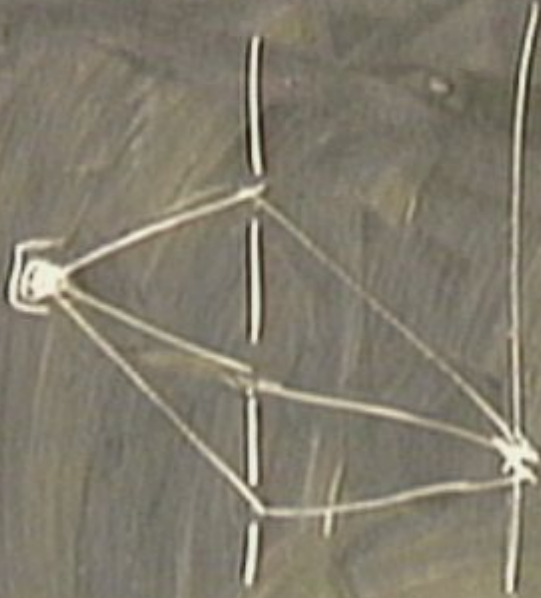
$+p \text{ OR } -p$



$+p$ AND $-p$



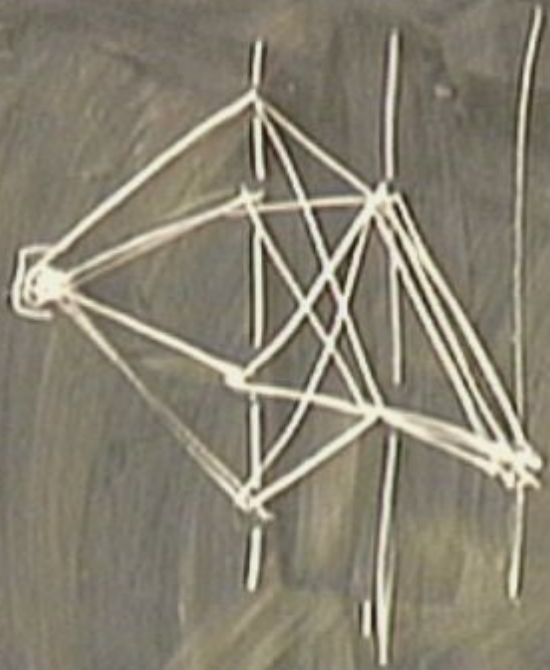
$+p$ OR $-p$



+p AND -p



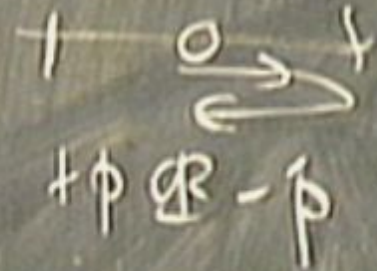
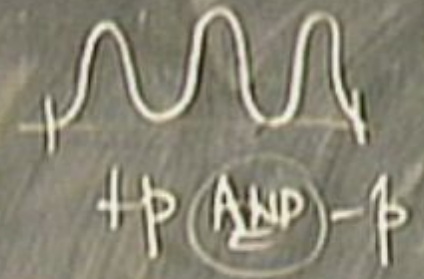
+p OR -p

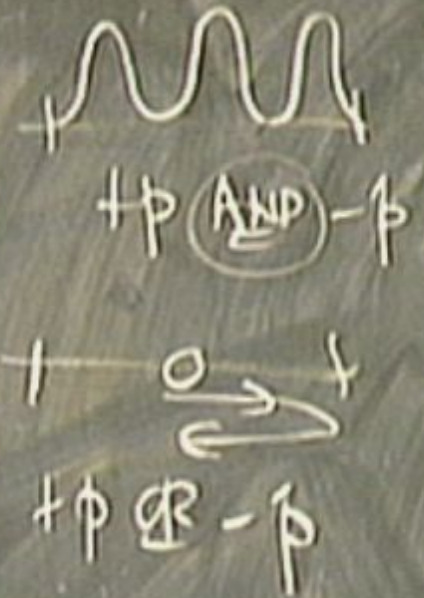


+p AND -p



+p OR -p





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