Title: Lecture - Quantum Foundations, PHYS 639

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Subject: Quantum Foundations

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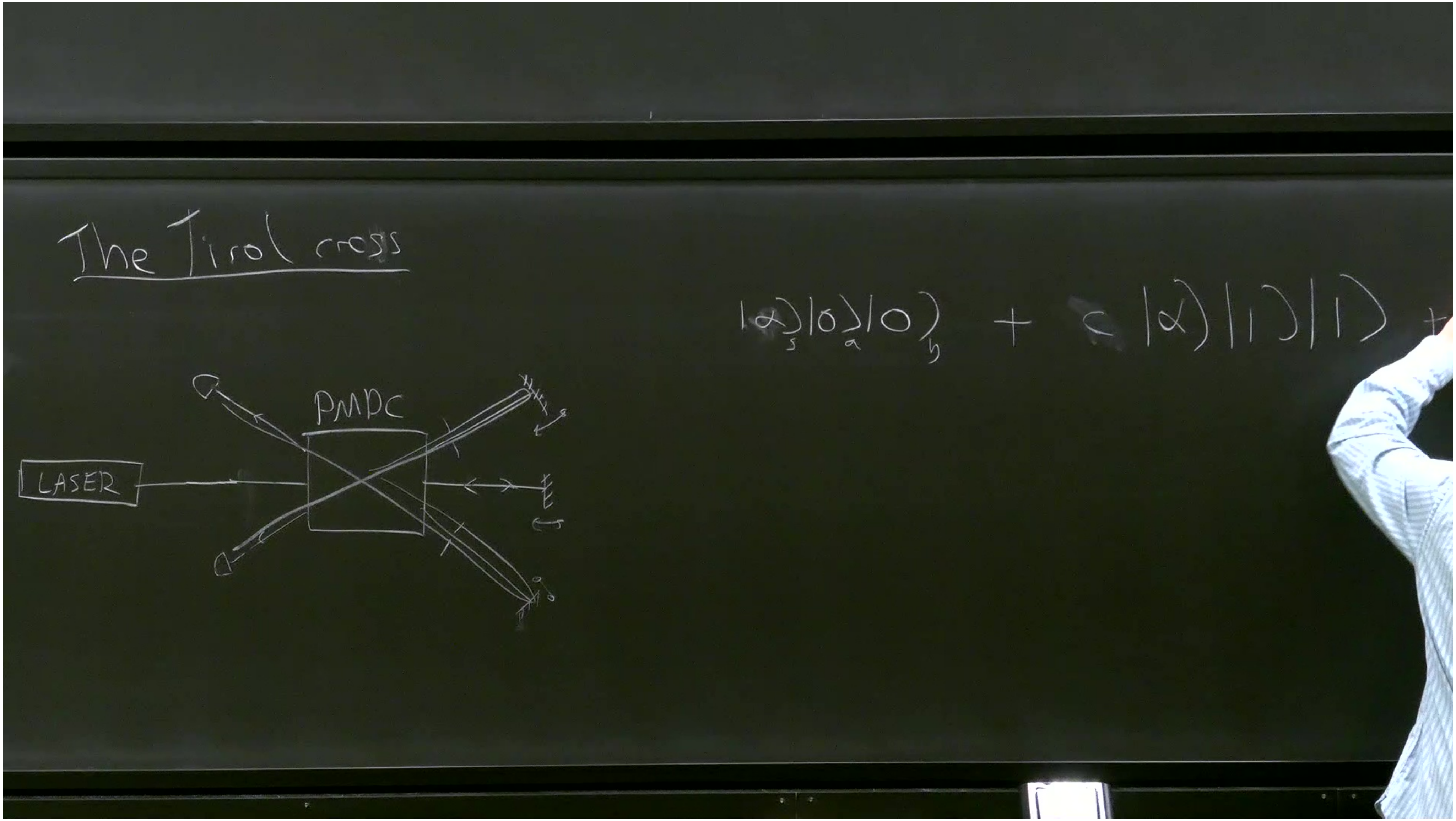
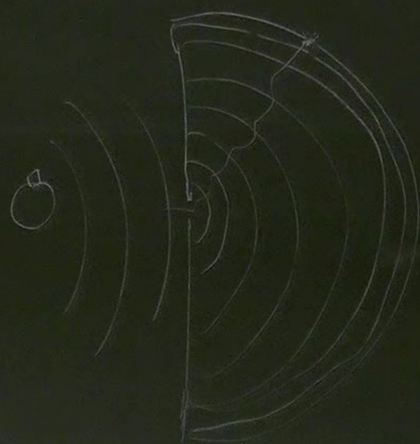

The Tirol cross
$|\alpha\rangle_s|0\rangle_a|0\rangle_b + c\,|\alpha\rangle|1\rangle|1\rangle +$
PMDC
LASER

$$|\alpha\rangle_s|0\rangle_a|0\rangle_b + c\,|\alpha\rangle|1\rangle|1\rangle + c e^{i\theta}|\alpha\rangle|1\rangle|1\rangle$$

$$|c+c|^2 = 4|c|^2$$

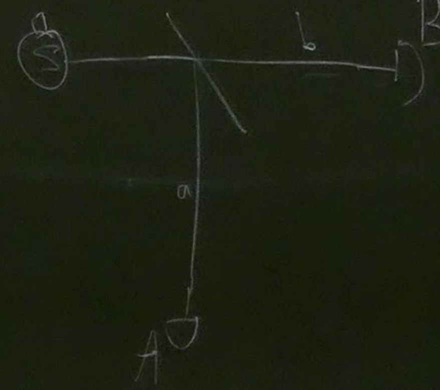
EPR 1935

Einstein 1927



completeness

locality.



Defn.

Completeness "every element of physical reality (epr) must have a counterpart in the physical theory"

ψ-completeness All elements of physical reality follow from the quantum state

$$[A=\alpha]_a \text{ is an epr iff } \langle\psi|\hat{P}_{(A=\alpha)_a}|\psi\rangle = 1$$

Suff. cond. for the existance of an epr "If, without in any way disturbi

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probability equal to unity)

exists an element of physic

certainty v. prob $= 1$

If prob$\left((A = \alpha)_a \middle| (B = \right.$

$$\lim_{N \to \infty} \frac{N - 100}{N} = 1$$

QBISM

and if measurement B does

then $\exists$ an epr $[A = \alpha]_a$ for

Suff. cond. for the existence of an epr

certainty v. prob = 1

$$\lim_{N\to\infty} \frac{N-100}{N} = 1$$

QBISM

"If, without in any way disturbing a sy

probability equal to unity) the v

exists an element of physical real

If $\text{prob}\left((A=\alpha)_a \,\middle|\, (B=\beta)_b\right) =$

and if measurement B does not dis

then $\exists$ an epr $[A=\alpha]_a$ for a ev

"If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this quantity"

If $\quad \text{prob}\left((A=\alpha)_a \,\middle|\, (B=\beta)_b \right) = 1$

and if measurement B does not disturb a

then $\exists$ an epr $[A=\alpha]_a$ for a even when we don't measure B

<u>locality</u> A system is undisturbed by choices made at spacelike separation from it.

We can prove

$$\begin{pmatrix}\text{QT}\\ \text{predictions}\end{pmatrix} \wedge (\psi\text{-completeness}) \wedge \text{locality} \Rightarrow \text{contradiction.}$$

$$\mathrm{prob}\left(\left(A = \begin{matrix} 1 \\ 0 \end{matrix} \right)_a \,\middle|\, \left(B = \begin{matrix} 0 \\ 1 \end{matrix} \right)_b \right) = 1$$

If we perform B and see $B = 0$

then $\exists$ epr $[A = 1]_a$

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$\overset{\text{locality}}{\Rightarrow}$ have an epr

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If we perform B and see $B=1$

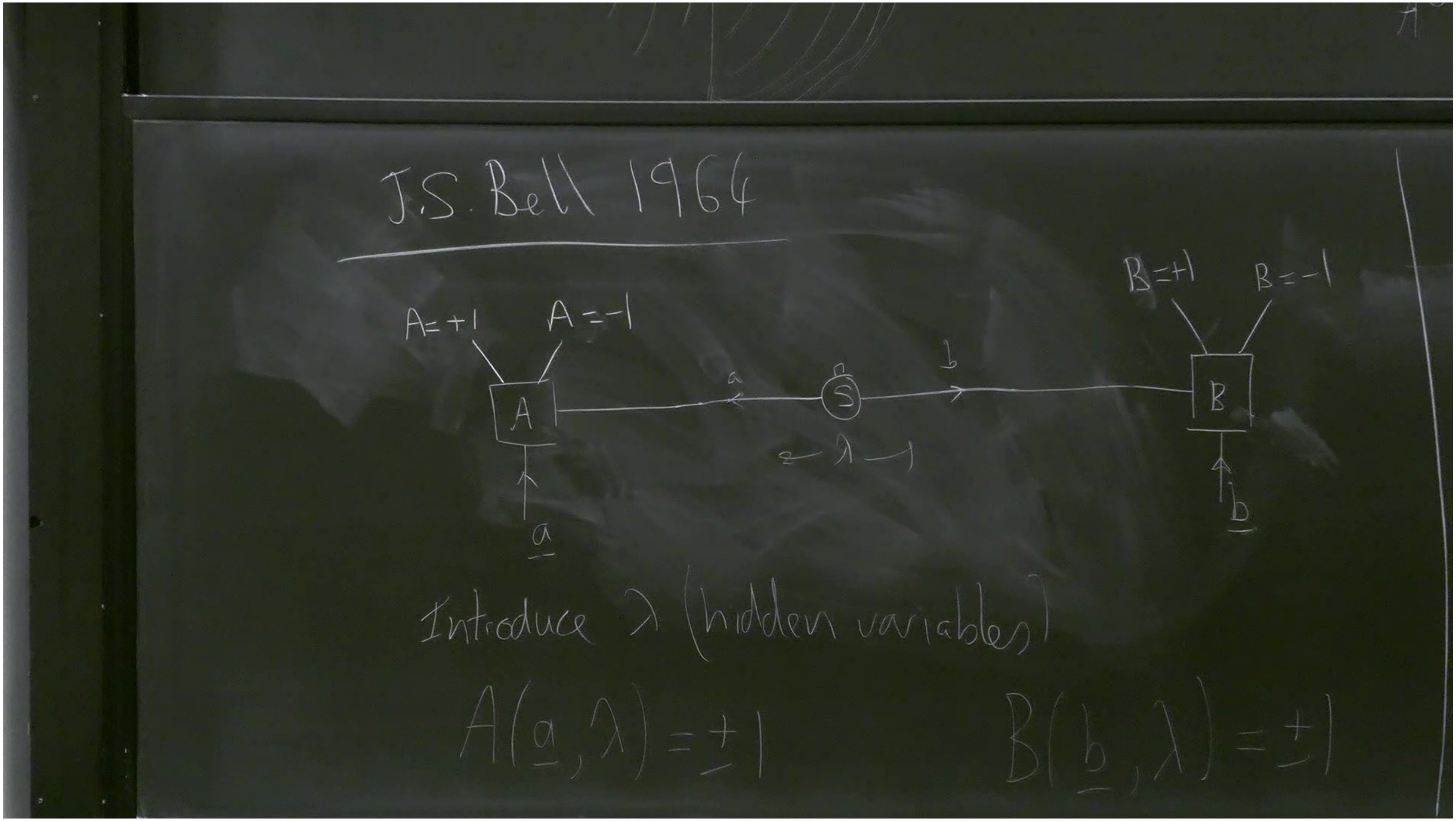
then $\exists$ epr $[A=0]_a$

$\overset{\text{locality}}{\Rightarrow}$ have an epr $[(A=\alpha)_a]$

even if we don't perform meas B.

But if $|\psi\rangle = \frac{1}{\sqrt{2}}\left(|a\rangle + |b\rangle\right)$

then $\langle\psi|\,\hat{P}_{A=\alpha}\,|\psi\rangle = \frac{1}{2}$


J.S. Bell 1964
A=+1
A=-1
B=+1
B=-1
A
S
B
a
b
λ
Introduce λ (hidden variables)
A(a, λ) = ±1
B(b, λ) = ±1

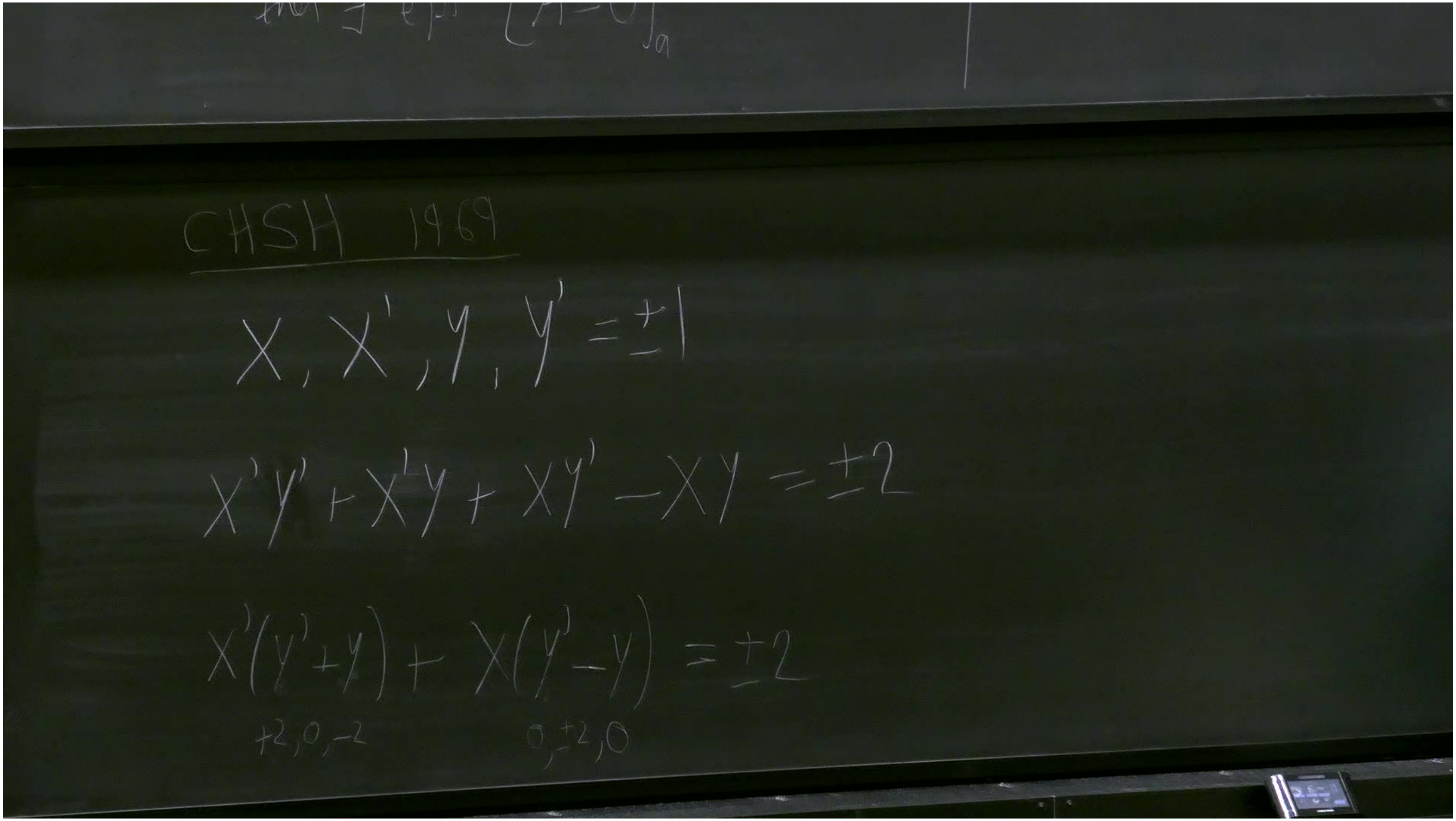
ψ-completeness   All elements of [illegible] quantum state

$$[A=\alpha]_{\alpha} \text{ is an epr iff } \langle\psi|\hat{P}_{(A=\alpha)_{\alpha}}|\psi\rangle = 1$$

$$E(\underline{a},\underline{b}) = \int_{\Gamma} A(\underline{a},\lambda)\, B(\underline{b},\lambda)\, \rho(\lambda)\, d\lambda$$

$\rho(\lambda)$ is a distribution over λ

$\rho(\lambda) \geq 0 \qquad \int_{\Gamma} \rho(\lambda)\, d\lambda = 1$


CHSH 1969
$X, X', y, y' = \pm 1$
$X'y' + X'y + Xy' - Xy = \pm 2$
$X'(y'+y) + X(y'-y) = \pm 2$
$+2, 0, -2$
$0, \pm 2, 0$