Lecture 2

- Thought Experiments
- Stern-Gerlach Experiments
- Analogy with mathematics of light
- Feynman's double slit thought experiment

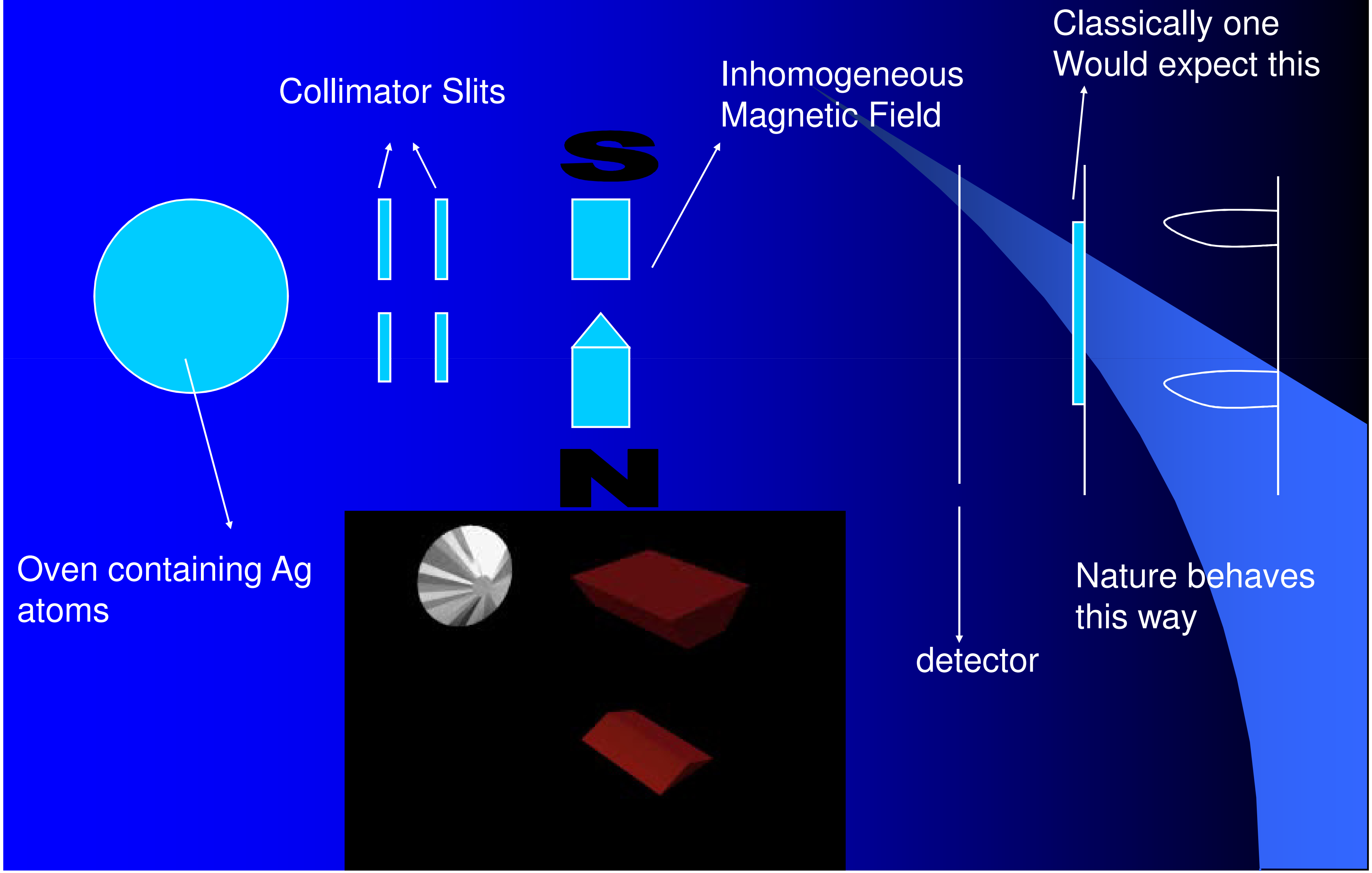
Thought Experiments

- We are formulating a new theory!
- Why are we formulating a new theory?
- In the last lecture tried to motivate you why we need a new theory?
- How?
- Radiation sometimes behaves as
  - Particles
  - Waves
- Same is true for Matter

Thought Experiments

- We must walk on a logical tight rope
- What is Feyman's logical tightrope?
- We have given up asking whether the electron is a particle or a wave
- What we demand from our theory is that given an experiment we must be able to tell whether it will behave as a particle or a wave.
- We need to develop a language for this new theory.
- We need to develop the Mathematics which the language of TRUTH which we all seek
- What Kind of Language we seek is the motivation for next few lectures.

Stern-Gerlach Experiment



Stern Gerlach Experiment unplugged

- Silver atom has 47 electrons where 46 electrons form a symmetrical electron cloud with no net angular momentum
- Neglect nuclear spin
- Atom has angular momentum –solely due to the intrinsic spin of the 47th electron
- Magnetic moment μ of the atom is proportional to electron spin
- If $\mu_z < 0$ (then $S_z > 0$) atom experiences an upward force & vice versa
- Beam will split according to the value of μ_z

$$\mu = \frac{e}{m_e c} S$$

$$Energy = -\vec{\mu}.\vec{B}$$

$$F_z = \mu_z \frac{\partial B}{\partial z}$$

Stern-Gerlach Experiment (contd)

- One can say it is an apparatus which measures the z component of μ ⇒ S_z
- If atoms randomly oriented
  - No preferred direction for the orientation of μ
  - Classically spinning object ⇒ μz will take all possible values between μ & -μ
- Experimentally we observe two distinct blobs
- Original silver beam into 2 distinct component
- Experiment was designed to test quantisation of space
  - Remember Bohr-Sommerfeld quantisation experiment

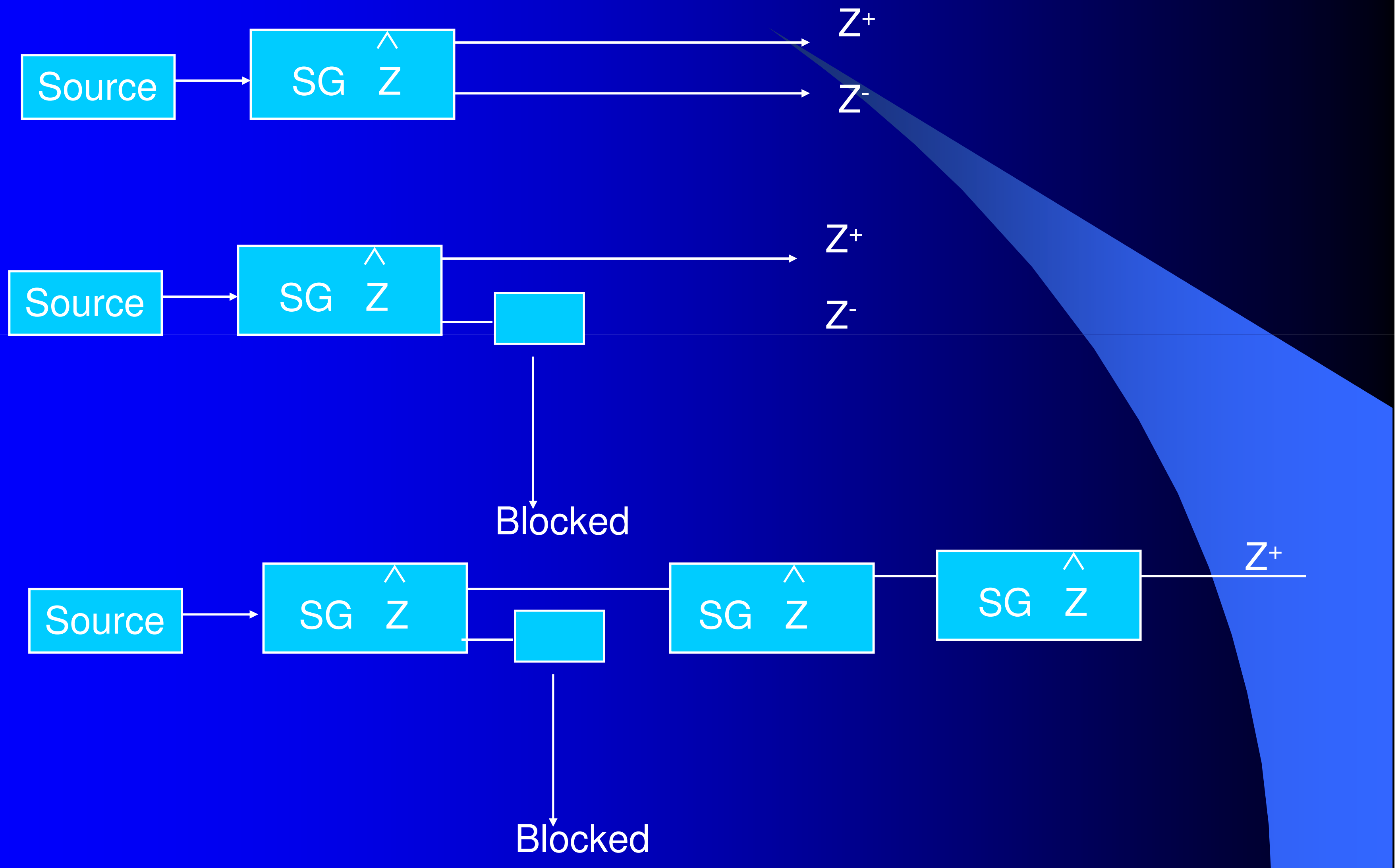
Physics Today December 2003

What have we learnt from the experiment

- Two possible values of the Z component of S observed S_Z^{UP} & S_Z^{down}
- Refer to them as S_Z^+ & S_Z^- $\Rightarrow$ Multiples of some fundamental constants, turns out to be $+\frac{\hbar}{2}$ & $-\frac{\hbar}{2}$
- Spin is quantised
- Nothing is sacred about the z direction, if our apparatus was in x direction we would have observed S_x^+ & S_x^- instead

SG $\hat{Z}$ ⟶ This box is the Stern Gerlach Apparatus with magnetic Field in the z direction

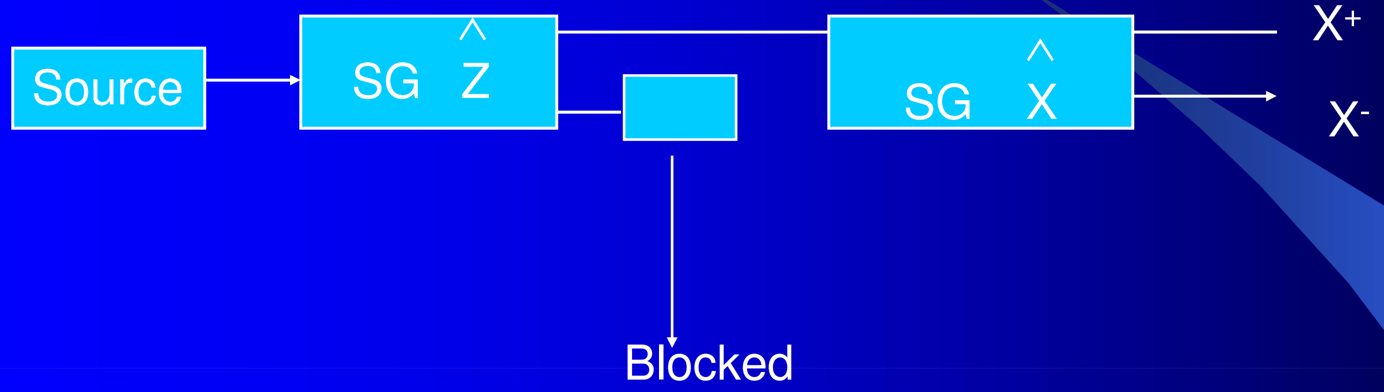
Thought Experiments start



Thought Experiment continues

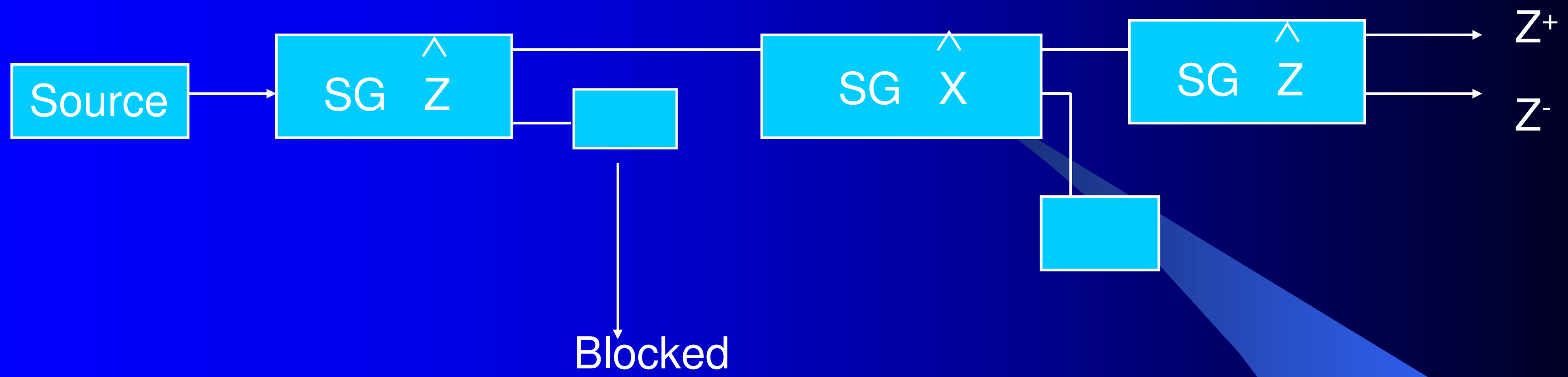
- No matter how many SG in z direction we put, there is only one beam coming out
- Silver atoms were oriented in all possible directions
- The Stern-Gerlach Apparatus which is a measuring device puts those atoms which were in all possible states in either one of the two states specific to the Apparatus
- Once the SG App. put it into one of the states repeated measurements did not disturb the system

Another thought experiment



Does It mean that 50% of the atoms in the S_z^+ beam coming out Of the first apparatus are made of atoms characterized by S_x^+ & 50% of the time by S_x^-

Testing the hypothesis



We Observe that from the final SG Z there are two beams Emerging

No way to explain as S_z^- was blocked

Only conclusion we can draw is that the second Measurement disturbed the first measurement

The Second measurement put the system in states specific To it. The third measurement which was different from 2nd

Conclusions from our experiment

- Measurements disturb a quantum system in an essential way
- The boxes are nothing but measurements
- Measurements put the QM System in one of the special states
- Any further measurement of the same variable does not change the state of the system
- Measurement of another variable may disturb the system and put it in one of its special states.

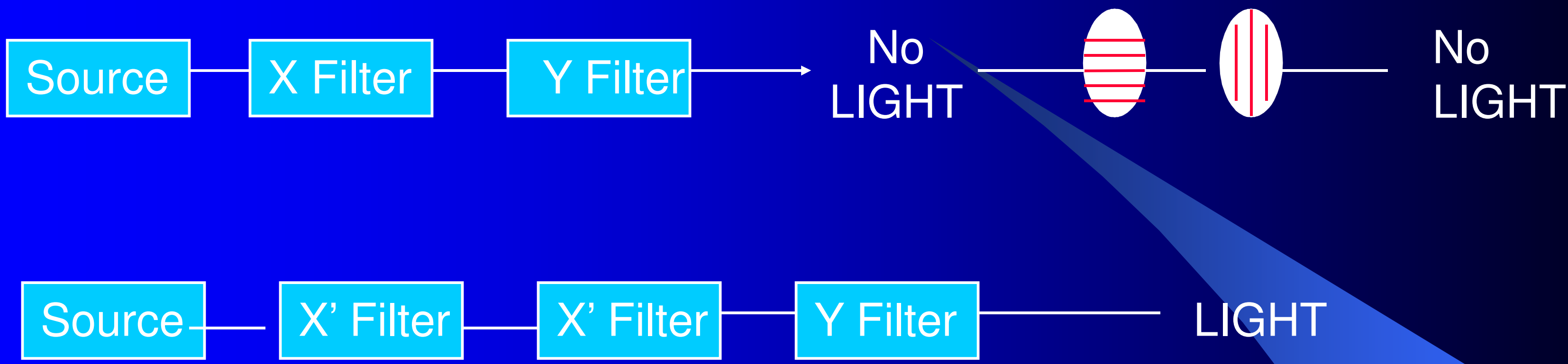
Complete Departure from Classical Physics

- Measurement of S_x destroys the information about S_z
  - We can never measure S_x & S_z together
    - Incompatible measurements
- How do you measure angular momentum of a spinning top, $L = I\omega$
  - Measure ω_x , ω_y , ω_z
  - No difficulty in specifying L_x L_y L_z

Analogy

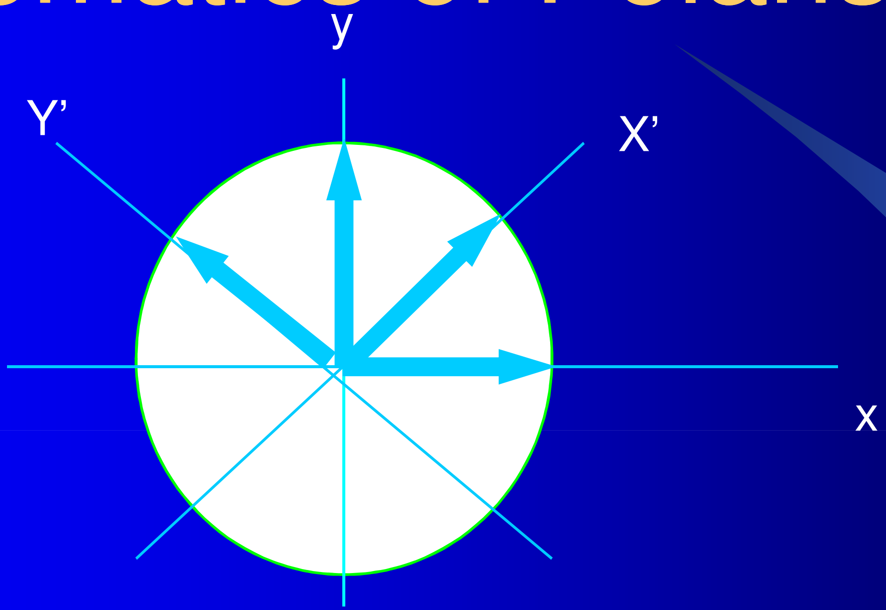
- Consider a monochromatic light wave propagating in Z direction & it is polarised in x direction $E = E_0 \hat{x} Cos(kz - \varpi t)$
- Similarly linearly polarised light in y direction is represented by $$E = E_0 \hat{y} Cos(kz - \varpi t)$$
- A filter which polarises light in the x direction is called an X filter and one which polarises light in y direction is called a y filter
- An X filter becomes a Y filter when rotated by 90°

An Experiment with Light



- The selection of x` filter destroyed the information about the previous state of polarisation of light
- Quite analogous to situation earlier
- Carry the analogy further
  - $S_z \pm$ x & y polarised light
  - $S_x \pm$ x` & y` polarised light

Mathematics of Polarisation



$$E_0 \hat{x}' Cos(kz - \omega t) = E_0 \left[\frac{1}{\sqrt{2}} \hat{x} Cos(kz - \omega t) + \frac{1}{\sqrt{2}} \hat{y} Sin(kz - \omega t) \right]$$

$$E_0 \hat{y}' Cos(kz - \omega t) = E_0 \left[-\frac{1}{\sqrt{2}} \hat{x} Cos(kz - \omega t) + \frac{1}{\sqrt{2}} \hat{y} Sin(kz - \omega t) \right]$$

Where to Get More Information

- Other training sessions
- List books, articles, electronic sources
- Consulting services, other sources