GEH1027 **2020/21 S2**
Einstein's Universe and Quantum Weirdness **Tutorial 4**

1) Work in groups **(15 mins) :**

Present to a friend the following Quantum Mysteries **clearly**.
a) The 2 slits Interference experiment for Electrons with spice agents
https://www.youtube.com/watch?v=Q1YqgPAtzho

b) Electron Microscope and Heisenberg Uncertainty Principle.
Discuss how $\Delta x \Delta p \approx \hbar$ is related to $\Delta E \Delta t \approx \hbar$.
Give an example of $\Delta E \Delta t \approx \hbar$ at work in a micro quantum system.
http://www.youtube.com/watch?v=KT7xJ0tjB4A (watch it before Tutorial class)

2) Work in groups **(10 mins):** Recall the 3 Epistemic Problems posted in Lecture 11 and see if you could **use Bohr's atomic model** to throw light into the following questions.

a) Why does the electron stay in the excited energy level for an unspecified period before it descends to a lower energy level? What is the physical mechanism that makes it wait?
b) Why the law of conservation of energy does not seem to hold true at these interim times of transition between states.
c) What is the physical mechanism that causes the creation of a photon, when the electron arrives at the lower energy level?

<u>3) To "Think" about it only</u>
Write **very briefly** (2 lines only) the significance for each of the following phenomena.
a) Planck's Blackbody Radiation **b)** Rutherford Scattering
c) Einstein's Photoelectric effect **d)** Franck-Hertz Experiment
e) Compton's experiment

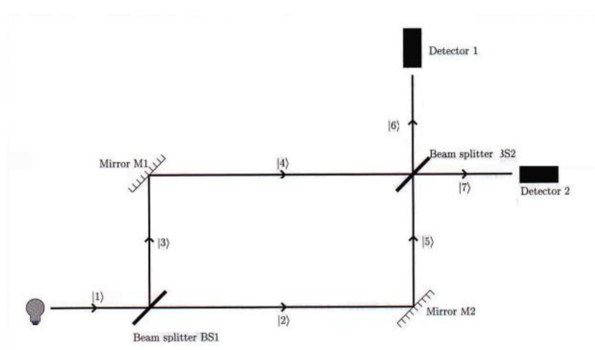
Form 1: $\Delta x \Delta p \geq \frac{\hbar}{2}$

Form 2: $\Delta E \Delta t \geq \frac{\hbar}{2}$

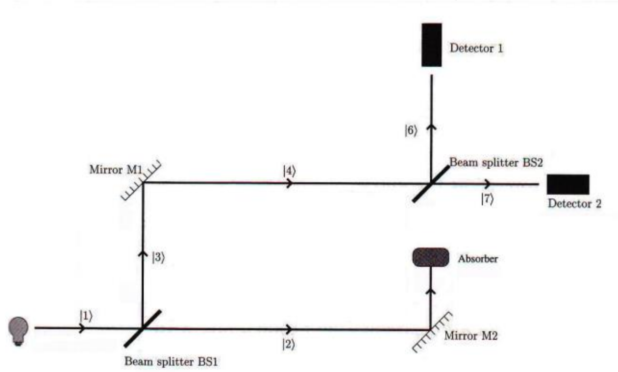
4) It is often said that a quantum particle has variable masses (i.e. not fixed mass). Does this surprise you as oppose to the classical particle? Can you give a reason?
Hint: Use the appropriate Heisenberg Uncertainty Principle.

↳ $\Delta E = (\Delta m)\underbrace{c^2}_{\text{↳ constant}}$

5) Consider the Mach-Zehnder Interferometer with 2 beam splitters (BS) below. When light is detected, detector 1 or detector 2 will click. We want to investigate what will happen when a single photon (weak light source) enters this interferometer.



a) Reason which detector will click more often and why?



b) We now block path 5 with a light absorber. **Reason carefully** again which detector will click more often and why?

Not only is the Universe stranger than we imagine, it is stranger than we can imagine. Sir A. Eddington

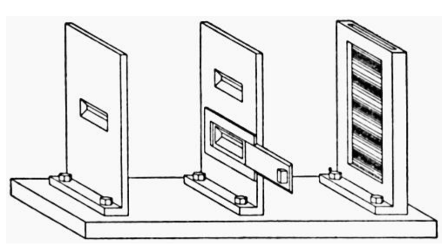
Optional Questions (Great debates between Einstein and Bohr …

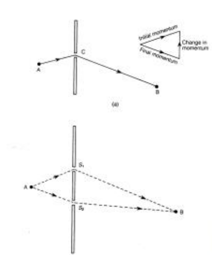
6) Recall the 2 slits experiment discussed in class.

At the 5th Solvay conference in 1927 (see picture below), Einstein raised doubts regarding Bohr's Quantum interpretation of the 2 slits experiment.

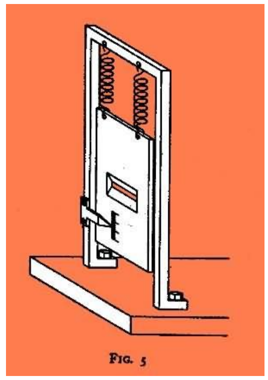
Einstein's doubt :

"When it (the photon) passes through the slit, it would impart a momentum to the slit arrangement. When arriving at a particular point on the target screen, the momentum transferred to the screen would be different for the 2 slits. By measuring the momentum, I know which slit the photon went through. So you cannot tell me that interference is produced only when we don't know anything about how photons go through the slits because here we have interference and I also know which slit the photon came through."





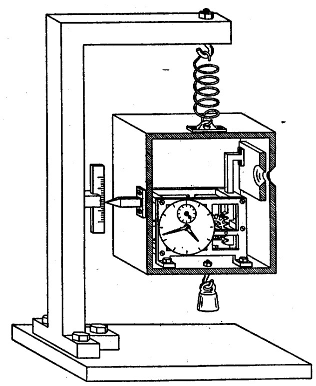
Can you comment or rebut Einstein's objection with the help of the figure below supplied by Bohr?



Bohr attached a scale and a pointer to the slit (figure above) so that one can measure the momentum of the slit by observing how much the pointer moves.

7) At the 6th Solvay conference in 1930, Einstein again raised doubts but this time regarding the Uncertainty principle, $\Delta E \Delta t \approx \hbar$

He considered the *gedanken* (a thought experiment) given in the figure below, we have a box installed with a shutter and a clock.



According to Einstein:

"At t_1 the clock opens the shutter releasing one photon out. The shutter is closed at t_2. By making $t = t_2 - t_1$ very small, we will know with high accuracy, the time when the photon escaped. In summary, the error Δt in t can be made as small as possible as we please.

How much energy went out with the photon? All we have to do is to compare the weight of the box before and after the photon has escaped. One would know accurately the energy of the photon.

So you see in the above both ΔE and Δt can be independently be made practically zero, violating the sacred uncertainty law, $\Delta E \Delta t \sim \hbar$"

Is there a problem in the above argument? Bohr has a splendid reply to Einstein.