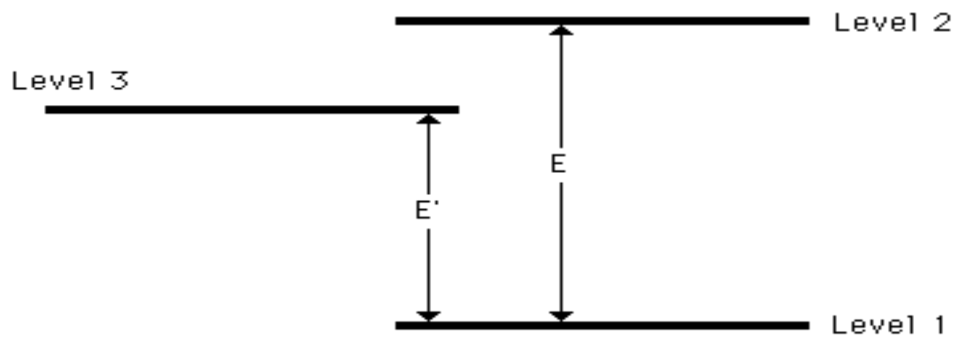
Watching the Quantum Pot

Consider a "**pot"** consisting of a few thousand Be ions (removed electrons). Such charged ions can be corralled by an electric-field into **ion trap = the quantum pot.**

This model is just like water molecules in pot on stove.

Now we want to make the pot of Be ions boil and see if watching them while they are trying to boil can stop boiling and demonstrate the collapse process,i.e., **can we actually see collapse process**.

At the start, the ions are all in same quantum energy level 1 of a 3-level system.



We apply a burst of radio waves with particular energy(frequency) $E = E_2 - E_1$ for exactly 256 msec, which causes all the ions to make a transition up to the higher energy level 2.

The upward transition is so rapid and the downward transition so slow that any ions that get to level 2 effectively remain there for duration of experiment.

this ion trap + radio waves = boiling pot

On a stove, heating supplies energy and boiling is the process of raising all molecules to higher energy (higher velocity) states which then allows them to escape from surface as steam.

The picture we just described happens if **do not measure the system at all**.

Now we ask how and when do the ions actually make a transition from one quantum state to other?

Remember, they only decide what state(choose among probabilities) they are in when that state is measured -- when an observer takes look at the ions, according to quantum mechanics.

Quantum mechanics says the transition is **GO-NOGO** process, an all or nothing affair; either the ion does or does not(via probabilities) change levels.

256 msec is the characteristic time in system when there is almost exactly 100% probability that any individual ion will have made the transition to level 2.

At 128 msec, there is exactly a 50-50 probability that any ion has made transition to level 2 or remained in level 1.

At any time in interval 0-256 msec, the system is in superposition of states with an appropriate mixture of probabilities

$$|\text{pot at time t}\rangle = \cos\left(\frac{2\pi t}{1.024}\right)|\textit{not boiled}\rangle + \sin\left(\frac{2\pi t}{1.024}\right)|\textit{boiled}\rangle$$

i.e.,

$$P(\textit{not boiled}) = \cos^2\left(\frac{2\pi t}{1.024}\right)$$

$$P(\textit{boiled}) = \sin^2\left(\frac{2\pi t}{1.024}\right)$$

When it is observed, we must always find the quantum system in definite state; we never see a superposition of states.

If could look at ions at 128 msec, theory says would have to choose between two possible states, just like Schrodinger's cat had to be dead or alive.

With equal probabilities, 1/2 choose level 1 and 1/2 choose level 2. This agrees with experiment.

NIST experimenters devised a neat technique for looking at the ions while they were making up their "minds" about which state to be in.

They sent a very brief pulse of laser light into quantum pot with photon energy $E' = E_3 - E_1$.

This laser burst interacts with the ions in pot so that the ions in level 2 are unaffected and all the ions remaining in level 1 are excited up to different higher energy level 3.

From level 3, they immediately ($\Delta t < 10^{-7}\,\text{sec}$) go back to level 1.

As they jump back, they emit characteristic photons of energy $E' = E_3 - E_1$. These fixed energy photons are detected and counted.

The number of photons counted tells us number of ions that were in level 1 when this special pulse was sent into pot.

When the ions were looked at once by the laser pulse after 128 msec , half were found in level 1.

This is what we should see according to quantum mechanics.

If the experimenters peeked 4 times during the 256 msec at equal intervals, at end of the experiment 5/8 of the ions were still in level 1 ..... not all in level 2 as was true when they did not look.

As stated earlier, at any arbitrary time t state of system is

$$\left|\text{pot at time t}\right\rangle = \cos\left(\frac{2\pi t}{1.024}\right)\left|\textit{not boiled}\right\rangle + \sin\left(\frac{2\pi t}{1.024}\right)\left|\textit{boiled}\right\rangle$$

In particular, this says that

$$\left|\text{pot at time } = 0\right\rangle = \left|\text{not boiled}\right\rangle$$
$$\left|\text{pot at time } = 256\right\rangle = \left|\text{boiled}\right\rangle$$

The probabilities are non-linear functions of time. This means that the transition rates are not constant in time, i.e., it varies depending where we are in the interval 0 - 256 msec.

Luckily, for us, the collapse mechanism intervenes to simplify the problem!

If we make 4 measurements each separated by 64 msecs, then here is what happens. At 64 msecs if we found a particle in state 1 (not boiled) then the collapse process resets the clock to $t = 0$ and to 256 msec if particle is found in state 2.

In particular, the probability of making a transition to state 2(boiled) during a time interval = $256/n$ = time between peeks, if it was in 1 at the beginning of interval, is given by

$$\sin^2\left(\frac{\pi}{2n}\right)$$

and hence probability of it remaining in state 1 (unboiled) is

$$1 - \sin^2\left(\frac{\pi}{2n}\right) = \cos^2\left(\frac{\pi}{2n}\right)$$

Similar arguments can be given for probabilities associated with starting in level 2.

If one uses quantum mechanics to calculate what happens after n

measurements one finds the prediction for probability of finding it in 2 after n measurements is given by

$$P(n) = \frac{1}{2}\left(1 - \cos\left(\frac{\pi}{2n}\right)\right)$$

which corresponds to $P = 3/8$ for $n = 4$ or $5/8$ are still unboiled. If they peeked 64 times (once every 4 msec), almost all ions were in level 1 at the end. In fact it goes like

n	$P(n)$
2	0.500
4	0.375
6	0.289
8	0.235
10	0.197
16	0.133
32	0.072
64	0.037
128	0.019

So, even though the radio waves were doing their best to boil the pot of ions, the watched quantum pot refused to boil. WHY?

The reason is that after 4 msec, the probability that a single ion will have made transition to level 2 is about 0.01%, so laser **finds** 99.99% of ions in level 1

It has, however, done more than that.

The act of looking at ions(measuring where they are) has collapsed the system back to level 1 quantum state as if $t = 0$ since that is where we found them.

Now the state(all in level 1 again) begins to once again try to become a mixture but 4 msec later we look again and collapse it again. At end of experiment ions have had no opportunity to make transition to level 2 without being observed and thus collapsed even though we are continuously supplying proper energy!!!

We are saying.......

The exact agreement with quantum theory shows that if it were possible to monitor the ions all time then none of them would ever change. If, as quantum mechanics suggests(according to some physicists), the world only exists because it is being observed, then it is also true that world only changes because it is not being observed all the time.