When no measurement is being made:

$|\Psi(0)> \rightarrow U(t)|\Psi(0)> = |\Psi(t)>$

That's called the unitary dynamics (a.k.a. the Schrödinger dynamics, a.k.a. Process II).

It's linear, continuous, and deterministic.

When a measurement of observable A gets made:

If

$|\Psi> = c_1|a_1> + c_2|a_2> + \ldots. + c_i|a_i> + \ldots$

then

$|\Psi> \rightarrow |a_i>$, for one of the i's, with probability $|c_i|^2$

and the result of the measurement is the corresponding eigenvlaue a_i.

(Collapse postulate & the Born Rule; a.k.a. Process I.)

That process is not linear, and it's not continuous, and it's not deterministic.

Some options for solving the measurement problem:

1. A physical theory of how, when, and why collapses happen.
2. An epistemic theory of collapses.
3. Collapses don't happen; they're merely apparent; what's really going on is this …
4. Anti-realist interpretation of quantum mechanics

An orthonormal basis for the electron:

$|\sigma, \psi^{S}{}_{x}\rangle$ where $|\sigma\rangle = |S_z+\rangle$ or $|S_z-\rangle$

An orthonormal basis for the detector:

$|\text{ready}\rangle$, $|+\rangle$, $|-\rangle$, $\{|\beta_i\rangle\}$

An orthonormal basis for Alice:

$|\text{waiting}\rangle$, $|\text{up}\rangle$, $|\text{down}\rangle$, $\{|\alpha_i\rangle\}$

An orthonormal basis for the composite system consisting of the electron, the device, and Alice:

$$|\sigma, \psi^{S}{}_{x}\rangle_e |\beta\rangle_d |\alpha\rangle_a$$

That's a direct product – not an inner product!

Assume:

1. This device is a good device for measuring z-spins.
2. Alice is able to use this device properly.

Assumption 1 implies:

$|S_z+, \psi^{S}{}_1\rangle_e |\text{ready}\rangle_d |\alpha\rangle_a \rightarrow |S_z+, \psi^{S}{}_2\rangle_e |+\rangle_d |\alpha\rangle_a$

and:

$|S_z-, \psi^{S}{}_1\rangle_e |\text{ready}\rangle_d |\alpha\rangle_a \rightarrow |S_z-, \psi^{S}{}_3\rangle_e |-\rangle_d |\alpha\rangle_a$

Assumption 2 implies:

$|S_z+, \psi^{S}{}_2\rangle_e |+\rangle_d |\text{waiting}\rangle_a \rightarrow |S_z+, \psi^{S}{}_2\rangle_e |+\rangle_d |\text{up}\rangle_a$

and:

$|S_z-, \psi^{S}{}_1\rangle_e |-\rangle_d |\text{waiting}\rangle_a \rightarrow |S_z-, \psi^{S}{}_3\rangle_e |-\rangle_d |\text{down}\rangle_a$

The time-evolution operator U is linear, i.e.:

$U(a|\Psi 1\rangle + b|\Psi\rangle) = aU|\Psi 1\rangle + bU|\Psi 2>$

So we can work out what actually happens in our measurement case.

$$
\begin{aligned}
&\left|S_x+,\psi_1^S\right\rangle_e \left|ready\right\rangle_d \left|waiting\right\rangle_a \\
&= \frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e \left|ready\right\rangle_d \left|waiting\right\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e \left|ready\right\rangle_d \left|waiting\right\rangle_a \\
&\rightarrow \frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e \left|+\right\rangle_d \left|waiting\right\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e \left|-\right\rangle_d \left|waiting\right\rangle_a \\
&\rightarrow \frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e \left|+\right\rangle_d \left|up\right\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e \left|-\right\rangle_d \left|down\right\rangle_a
\end{aligned}
$$

$$\left|S_x+,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a$$
$$=\frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a+\frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a$$
$$\rightarrow\frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e\left|+\right\rangle_d\left|waiting\right\rangle_a+\frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e\left|-\right\rangle_d\left|waiting\right\rangle_a$$
$$\rightarrow\frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e\left|+\right\rangle_d\left|up\right\rangle_a+\frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e\left|-\right\rangle_d\left|down\right\rangle_a$$

Maybe: with 50% probability this happens:

$$\left|S_x+,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a$$
$$=\frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a+\frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a$$
$$\rightarrow\left|S_z+,\psi_2^S\right\rangle_e\left|+\right\rangle_d\left|waiting\right\rangle_a$$
$$\rightarrow\left|S_z+,\psi_2^S\right\rangle_e\left|+\right\rangle_d\left|up\right\rangle_a$$

and with 50% this happens:

$$\left|S_x+,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a$$
$$=\frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a+\frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e\left|ready\right\rangle_d\left|waiting\right\rangle_a$$
$$\rightarrow\left|S_z-,\psi_3^S\right\rangle_e\left|-\right\rangle_d\left|waiting\right\rangle_a$$
$$\rightarrow\left|S_z-,\psi_3^S\right\rangle_e\left|-\right\rangle_d\left|down\right\rangle_a$$

$$\left|S_x+,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a$$
$$=\frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a$$
$$\rightarrow \frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e |+\rangle_d |waiting\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e |-\rangle_d |waiting\rangle_a$$
$$\rightarrow \frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e |+\rangle_d |up\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e |-\rangle_d |down\rangle_a$$

Or instead, maybe with 50% this happens:

$$\left|S_x+,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a$$
$$=\frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a$$
$$\rightarrow \frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e |+\rangle_d |waiting\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e |-\rangle_d |waiting\rangle_a$$
$$\rightarrow \left|S_z+,\psi_2^S\right\rangle_e |+\rangle_d |up\rangle_a$$

and with 50% this happens:

$$\left|S_x+,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a$$
$$=\frac{1}{\sqrt{2}}\left|S_z+,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_1^S\right\rangle_e |ready\rangle_d |waiting\rangle_a$$
$$\rightarrow \frac{1}{\sqrt{2}}\left|S_z+,\psi_2^S\right\rangle_e |+\rangle_d |waiting\rangle_a + \frac{1}{\sqrt{2}}\left|S_z-,\psi_3^S\right\rangle_e |-\rangle_d |waiting\rangle_a$$
$$\rightarrow \left|S_z-,\psi_3^S\right\rangle_e |-\rangle_d |down\rangle_a$$

Here are some things we don't understand:

When do the collapses happen?
What makes them just then, but at no other time?
Is the collapse a real physical process –

> or alternatively, is it a change in our state of knowledge –
> or alternatively, is it something that doesn't really happen at all but only appears to happen?

Here are some more questions we would like to know the answers to:

What is the wavefunction/state-vector?

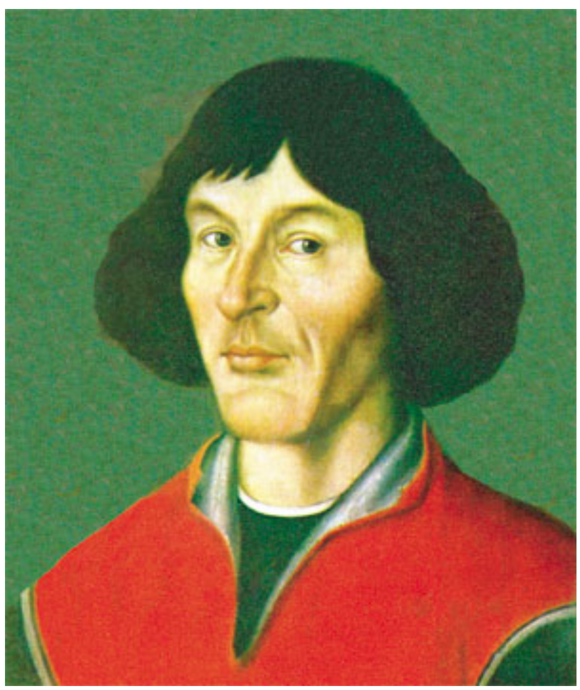
What we know about it is that there's a certain algorithm linking it to probabilities. -- but what are those probabilities? Are they credences? Chances? Frequencies? or something else?

And what is this wavefunction-thingy that's connected to the probabilities and why does it give rise to probabilities in the way it does?

When a system is in a superposition, or an entangled state, what is really going on with it?

From the Preface to Copernicus's book *On the Revolutions of the Celestial Spheres*:

There have already been widespread reports about the novel hypotheses of this work, which declares that the earth moves whereas the sun is at rest in the center of the universe. Hence certain scholars, I have no doubt, are deeply offended and believe that the liberal arts, which were established long ago on a sound basis, should not be thrown into confusion. But if these men are willing to examine the matter closely, they will find that the author of this work has done nothing blameworthy. For it is the duty of an astronomer to compose the history of the celestial motions through careful and expert study. Then he must conceive and devise the causes of these motions or hypotheses about them. Since he cannot in any way attain to the true causes, he will adopt whatever suppositions enable the motions to be computed correctly from the principles of geometry for the future as well as for the past. The present author has performed both these duties excellently. For these hypotheses need not be true nor even probable. On the contrary, if they provide a calculus consistent with the observations, that alone is enough.

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Elements of the Copenhagen Interpretation:

- Heisenberg Cut
  - The observer side must be described using classical concepts;
  - The system side must be described using quantum mechanics.
- State-vector completeness
- Eigenvector-eigenvalue link
- Collapses induced by measurements
- Stochastic interpretation of the Born Rule probabilities
- Complimentarity: Classical concepts cannot be applied to physical reality all at once.

Some Interpretative Options:

	Copenhagen (Bohr, Heisenberg, Pauli)	Hidden-variables (e.g. Bohm)	Dynamical Collapse (e.g., Ghirardi-Rimini-Weber)	Everett (e.g., many-worlds)
QM applicable to whole world at once?	No	Yes	Yes	Yes
Wave-function completeness?	Yes	No	Yes	Yes
Eigenvalue-Eigenvector link?	Yes	No	It's complicated	It's complicated
State-vector physical or epistemic?	?	Epistemic (?)	Physical	Physical
Collapses happen?	Yes	Only apparently	Yes	No
Collapses induced by measurements, or something else?	Measurements	Not applicable	Something else	Not applicable

	Easy-breezy anti-realist interpretation
QM applicable to whole world at once?	Sure
Wave-function completeness?	No
Eigenvalue-Eigenvector link?	No
State-vector physical or epistemic?	It doesn't exist
Collapses happen?	No
Collpases induced by measurements, or something else?	Not applicable