

Lesson 2: Uncertainty Principle

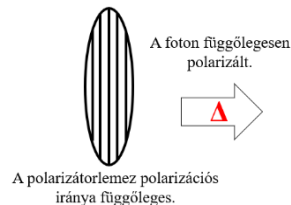
Task 1. A beam of N photons has passed through the polariser P1. These photons are emitted onto a second polariser P2, which is rotated by an angle θ with respect to the maximum transmission. Tick the correct answers in the table.

The photons certainly pass through P2 (i.e. the probability of transmission is 1) if P1 and P2 have the angle:	a) $\theta = \underline{\hspace{2cm}}$
	b) $\theta = 0^\circ$ (parallel)
	c) $\theta = 90^\circ$ (perpendicular)
The photons certainly absorb on P2 (i.e. the probability of transmission is 0) if P1 and P2 have the angle:	a) $\theta = \underline{\hspace{2cm}}$
	b) $\theta = 0^\circ$ (parallel)
	c) $\theta = 90^\circ$ (perpendicular)

Photons acquire a **property** after passing through P1, which remain after passing through P2 (P1 and P2 have the same orientation).

The polarisation properties of photons are difficult to visualise, so we use the notation chosen below.

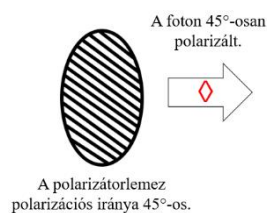
- Symbol „ Δ ” represents photons with vertical polarisation property.



- Symbol „ $*$ ” represents photons with horizontal polarisation property.



- Symbol „ \diamond ” represents photons with 45° polarisation property (relative to horizontal).



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Task 2. Consider a polarised beam of photons.

A) Complete the table and circle the corresponding column in the last column.

	Property of the incident photon.	Direction of the polariser.	The probability of transmission.	The photons never/always go through the polariser.
1)	*	H	1	Never / Always
2)	*	V	0	Never / Always
3)	Δ	H	0	Never / Always
4)	Δ	V	1	Never / Always

B) Choose the correct one from the boxes below:

Photon cannot possess property * and Δ simultaneously.

Photons can possess property * and Δ simultaneously.


Properties Δ and * are not mutually exclusive.

Properties Δ and * are mutually exclusive.

Task 3. The results of experiments are shown below. Plot the passing photons in the arrows in the diagram (indicating their expected number and polarisation properties).

a)


A polarizátorlemez iránya 45°-os.



A beeső fotonok függőlegesen polarizáltak.

b)

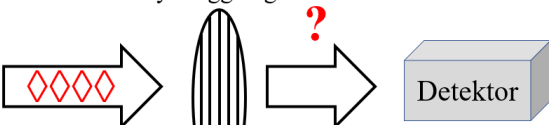
A polarizátorlemez iránya 45°-os.



A beeső fotonok vízszintesen polarizáltak.

c)

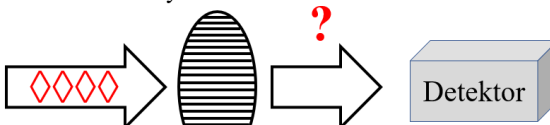
A polarizátorlemez iránya függőleges.



A beeső fotonok 45°-osan polarizáltak.

d)

A polarizátorlemez iránya vízszintes.



A beeső fotonok 45°-osan polarizáltak.

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Task 4. Complete the table below!

	The property of incident photons.	The permitted direction of the polariser.	The probability of transmission.	Will a single photon go through?			Property of the transmitted photon.		
				Never	Always	Half of the cases	\diamond	Δ	*
1)	\diamond	45°	1	Never	Always	Half of the cases	\diamond	Δ	*
2)	\diamond	V	1/2	Never	Always	Half of the cases	\diamond	Δ	*
3)	\diamond	H	1/2	Never	Always	Half of the cases	\diamond	Δ	*
4)	Δ	45°	1/2	Never	Always	Half of the cases	\diamond	Δ	*
5)	*	45°	1/2	Never	Always	Half of the cases	\diamond	Δ	*

Task 5. Consider two concepts.

- Two properties are **mutually exclusive**, if the possession of one property allows us to imply *certainty* the non-possession of the other property. The properties can always be investigated by measurements, and the observable properties via a given measurement are always mutually exclusive properties, and the sum of the probability of measuring each mutually exclusive properties is 1.
- Two properties are **incompatible**, if the possession of one property makes the possession of the other one *uncertain*. If a measurement is probabilistic, then the property of the examined quantum object is incompatible with the possible observable properties.

What conclusions can we draw from the experimental results? Circle them!

Properties Δ and \diamond
(or * and \diamond) are
mutually exclusive.

Properties Δ and \diamond are
incompatible.

Photons cannot
possess properties Δ
and * simultaneously.

Properties Δ and \diamond are
compatible.

Photons can possess
properties Δ and *
simultaneously.

Justify your choices!

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Task 6. A single photon has passed through a polariser with vertical permitted direction and therefore has the property Δ . Can we say that it possesses the property $*$ and what measurement can we use to prove the truth of our statement?

Task 7. A single photon is polarized 45° therefore it has the property \diamond . Can we say that it possesses the properties $*$ or Δ and what measurement can we use to prove the truth of our statement?

We explored the **uncertainty principle**: there are incompatible properties in quantum physics. Two incompatible properties cannot be certainly associated with a system simultaneously. The property that cannot be certainly associated with a system is uncertain. This uncertain property can be measured with a given probability.

As long as in classical physics all properties are observable, in quantum physics a quantum object can possess a property which is incompatible with the observable properties. If the property of a single photon is incompatible with the observable properties, we say, it is in **superposition**. The existence of the superposition is called the **superposition principle**.