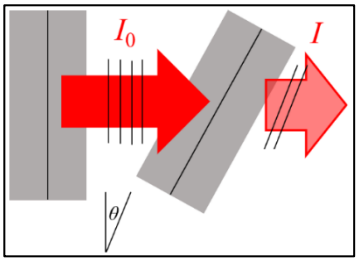
ELTE EÖTVÖS LORÁND UNIVERSITY

Lesson 1: A New Interpretation of Malus Law

A polarised light beam of intensity I_0 are emitted onto a polariser. From the measurements, we the intensity of the transmitted light I can be calculated from the following table, where θ is the angle of change of polarisation.

The experiments can also be interpreted by accepting that light consists of photons, which are undividable (i.e., the number of photons is always an integer) and undistinguishable. The intensity of light is proportional to the number of photons N (if the light is monochromatic). Thus, we have added to the above table a column for the number of photons (where N is the number of transmitted photons and N_0 is the number of incident photons).

θ	$I/I_0 = N/N_0$
0°	1
30°	3/4
45°	1/2
60°	1/4
90°	0



Task 1. A vertically polarised light beam consists of N_0 photons are emitted on a polariser with 45° permitted direction (we always give the angle relative to horizontal). After the polariser, we put a detector which measure the number of transmitted photons.

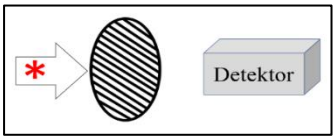
a) Draw a sematic picture of the event!

b) How many (N) photons will be detected? $N =$ _____ .

c) What is the permitted direction of the polariser when N / N_0 is…

- …1? _____
- …0? _____
- …1/2? _____

Task 2. What would the Malus law predict if the light beam were so low in intensity that only a single horizontally polarised photon is emitted onto a polariser with 45° permitted direction at a time? How would you interpret the result in the sense that the photons are undividable? The * in the drawing represents the horizontally polarised photon.



a) Answer:

b) Should we change the answers to questions **b)** and **c)** in **Task 1** in this case? Justify your answer!

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c) What does the fraction $I/I_0 = N/N_0$ in Malus law mean in the case of single photons?

Task 3. What is the probability of the transmission of a photon with 45° polarisation through a polariser with the following permitted directions:

V vertical? _____ **H** horizontal? _____ 45°? _____

Task 4. 10 horizontally (**H**) polarised photons are emitted onto a polarizer. How many photons would you expect to be detected by the detector located beyond the polariser in each of the following cases?

The polariser has…

a) …horizontal permitted direction (**H**),	**b)** …vertical (**V**) permitted direction,	**c)** …45° permitted direction,	**d)** …30° permitted direction (relative to **H**).

Task 5. Perform the previous thought experiments with JQM.

A) How many photons did the detector detect in each case in the previous exercise? Give the numbers!

a) _____	**b)** _____	**c)** _____	**d)** _____

B) Explain in which cases were the expectation correct! Why?

Task 6. A light beam with 30° polarization contains 100 photons. This beam is emitted onto a polariser with horizontal permitted direction. How many photons are expected to be detected? What is the result of the simulation experiment JQM?

The orientation of the polariser	Expected number of transmitted photons (prediction)	The measured number of transmitted photons (experiment)
• Horizontal (**H**)		
• Vertical (**V**)		
• 30° relative to the horizontal		

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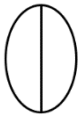
Task 7. Based on the results of the simulation experiments, what statistical meaning can be attributed to the Malus law?

Task 8. Complete the table. The first column shows the property of the first polariser, which determines the polarisation of transmitted photons. N_0 photons passed through this. The second column gives the orientation of the second polariser onto which the photons are emitted.

We polarise the beam of photons, N_0 passed through the polariser.	This N_0 photons are emitted onto the 2nd polariser.	The probability of transmission through the 2nd polariser.	The polarization property of transmitted photons.
 F	 F		
	 V		
	 45°		
	 30°		
	 60°		

- Are there certain events (i.e., events with probability 0 or 1)? What are they?

- How could the processes be described in terms of the polarisation properties of photons?

- Are there cases where the transmission of a photon cannot be certainly predicted? What are they?

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A summary of what you have learned:

- Quantum mechanical changes can be described by probabilities and these probabilities can be determined. This is called the **probability law**.
- Since photons are indistinguishable, large number of repeated measurements on a single photon is equivalent to measuring once a large number of photons at the same time. When we examine many photons (in either way) we also refer to photons as an **ensemble**.
- Probabilistic events are **collectively predictable**. For large number of photons, you can tell what fraction of photons will pass through a polariser because the measured average is close to the expected value. The empirical relative frequency of an event (the frequency of the measured event divided by the number of measurements), for very many measurements, is approximately equal with the theoretical probability of an event.
- For a large number of photons, the probabilistic interpretation gives back the classical Malus law as the expected number of transmitted photons. **The classical theory of light polarisation appears in a limit.**