24th International Young Physicists’ Tournament

Team of Belarus

Iran Tehran
July 2011

Ministry of Education
Republic of Belarus
Belarusian team

Problem #17
“Vikings”
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According to a legend, Vikings were able to navigate in an ocean even during overcast (dull) weather using tourmaline crystals. Study how it is possible to navigate using a polarizing material. What is the accuracy of the method?
Stages

- What is tourmaline crystal?
- Polarization of light in the atmosphere

Method of navigation

Experiment

Accuracy
Part 1

What is a tourmaline crystal?
What is tourmaline?

Physical properties:

• Polarizer is a device that converts a beam of electromagnetic waves (light) of undefined or mixed polarization into a beam with well-defined polarization.
Tourmaline plate (experiment)
Polarizer

polarizer

↓
Experimental setup

- Laser pointer
- Polarizer
- Sensor
- Laptop
Illumination against angle

\[ I = A \cos^2 \alpha \]

Polarizer

- Polarization of light
- Method of navigation
- Accuracy
Part 2

Polarization of light in the atmosphere
Earth’s atmosphere

- Troposphere
- Stratosphere
- Mesosphere
- Thermosphere
- Exosphere

- Rayleigh scattering

- Fluctuations of density
- Size of fluctuations <0.03λ

- Polarizer - Polarization of light - Method of navigation - Accuracy
Physical model of the Rayleigh scattering in the atmosphere.

An electric dipole is a classical model of scatterer.
Part 2. Polarization of light in the atmosphere

Polarized light

\[ P = \frac{\sin^2 \phi}{1 + \cos^2 \phi} \]

\( \phi \) is the angle of scattering

Volume with dipoles

\( P \) is the degree of polarization
Part 2. Polarization of light in the atmosphere

Rays

$\phi$ – angle of scattering

$\phi$ – maximal degree of polarization
Panoramic photo

Brightness, %

Method of navigation - Accuracy
Polarizer - Polarization of light - Method of navigation - Accuracy

Polarization direction

\[ \varphi_1 = 90^\circ \]
\[ \varphi_2 \neq 90^\circ \]
\[ P_1 = P_{\text{max}} \]
\[ P_2 < P_{\text{max}} \]
Polarization direction

A

B

C

Intensity
Polarization direction

Rays
Part 3

Method of navigation
What we should do?

1. Find the location of the Sun

2. Find direction to the north, south, east and west
How can we find the location of the Sun?

1. Measurement of intensity (Vikings did not have sensors)

2. Polarization direction (You need only polarizer and eyes)
Where can we see polarized light?

- Clouds

$d \approx 1-10$ micrometers

$d > 0.03 \lambda$

Rayleigh scattering

Unpolarized light
Cloudy weather
The orientation of the polarizer
Finding clear points on the sky. Finding location of Sun.
Finding sides of the world

- calendar
- sundial
Part 4
Accuracy
Polarizer

- Unideal polarizer
- We can not accurately determine the time of complete darkening

$\pm 4^\circ$

Finding location of the Sun

- Connection of two perpendicular

Finding direction on North

- Location of an artificial light source
- Error of the calendar
- Error of angle

$\pm 3^\circ$

$\pm 10^\circ$
Conclusions

1. Vikings could navigate by polarized light.
2. Light is polarized by scattering on fluctuations of optical density in the Earth’s atmosphere.
3. Rayleigh scattering is simple physical model for explanation polarized light.
4. There is a certain polarization direction in the sky (on a tangent to the circles, which are held symmetrically from the Sun)
5. Any other polarizer can be used instead of tourmaline
6. The greatest error appears in determining the position of the Sun
References

- Matveev, Optics (1989)
Thank you for attention!

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Results

1. We checked ability of navigation with help polarized light
2. We found the direction of polarization of light in the sky
3. We have found where we can take the measurement error for the chosen method of navigation
Reemission

\[ I(\phi) \sim A(1 + \cos^2 \phi) \]
Degree of polarization

\[
\cos \varphi = \frac{2 - \cos^2 \theta - \cos^2 \alpha + 2 \cos \theta \cos \alpha \cos \beta}{2}
\]

\[
P = \frac{\sin^2 \varphi}{1 + \cos^2 \varphi}
\]

\[
I(\varphi) \sim A(1 + \cos^2 \varphi)
\]
Rays

Wave surfaces

- maximal intensity
Finding the sides of the world using Sun and clock

Until 13 hours

After 13 hours
Scattering on clouds

- dense environment
- large particles
Finding the sides of the world using the midday shadow

\[ \text{flame} \]
Polarization direction

Φ - angle of scattering
Φ = constant for points in a circle
Polarization direction

- polarization direction
Polarization direction

$\phi$ is angle of dispersion

$\phi =$ constant for points in a circle
Sundial

- latitude
Finding the sides of the world

- Polarizer
- Polarization of light
- Method of navigation
- Accuracy
Sundial

α – angle of elevation