5. Mirage

Create a mirage like a road or desert mirage in a laboratory and study its parameters.
What are the weather conditions, when a mirage occurs?

- Significant temperature difference between the media
  a) Hot road or desert sand and cooler air;
  b) Cool sea or lake surface nad warm air.
- Big distance between the observer and the observed object
- Preferably no wind – to stabilize the mirage.

http://www.sundog.clara.co.uk/atoptics/phenom.htm
Light in an optically non-uniform medium

When a light beam is passing through media, which have different refractive index, it refracts.

\[ n_3 > n_2 > n_1 \]

For each refraction, we can write:

\[ n_1 \sin \alpha_1 = n_2 \sin \alpha_2 \]
\[ n_2 \sin \alpha_2 = n_3 \sin \alpha_3 \]
\[ n_3 \sin \alpha_3 = \ldots \]

General conclusion:

\[ n \sin \alpha = \text{const} \]
Light in an optically non-uniform medium

When the number of layers with different refractive index is very big, we get the continuous refractive index distribution.

The light ray path is a curve.
Medium with continuous distribution of refractive index

We’ve filled the bottom of an aquarium full of water with a natrium chloride (NaCl) solution (much denser than water). Hence the solution has different refractive index on different depths.
Light rays path

Important observation: light rays curves are convexed in the direction of decreasing optical density.

\( h \) – NaCl concentration

\( H \) – height above the bottom
Temperature is decreasing with height, its refractive index is increasing, so the light beam curve is concaved in the downwards direction.
Types of mirages

Distribution of the refractive index of air

Difference of temperatures between a certain surface and the air.

Refrective index decreasing with height

Refrective index increasing with height

Partially increasing, partially decreasing with height refractive index.

EXTERIOR MIRAGE

INFERIOR MIRAGE

‘FATA-MORGANA’
Road or desert – inferior mirage
Sea, lake, desert – exterior mirage
‘Fata – Morgana’
Natural mirage vs. laboratory conditions

Limited laboratory space

Much smaller distances than in natural mirages

Smaller objects observed

Much higher temperatures

Models instead of realistic objects (e.g., mountains)

Heating setup: Bunsen burners, propane-butane
Our experimental setup

- Alluminium plate (200 X 50 X 0,3 cm) covered with quartz sand
- 5 Bunsen burners with propane-butane

Setup applied by R.W. Wood in 1899.
Our experimental setup
Obtained mirage
Obtained mirage
Obtained mirage
Second experimental setup

Consisted of a small alluminium plate (20 X 20 X 0,5 cm), heated by a gas burner.
Obtained mirage
A bloc made of plexi is a very good experimental medium.
Constant gradient of refractive index when temperature gradient attached:

\[
\frac{dn}{dx} = k \quad \Rightarrow \quad n(x) = n_0 + kx
\]

\[
\frac{df(x_0)}{dx} = \tan \varphi = \frac{\sin \varphi}{\sqrt{1 - \cos^2 \varphi}}
\]

\[
n(x_0) \sin \varphi = n_1 \sin 0^\circ = n_1
\]
Laser light experiment
‘Desert’ mirage
Simulation

Min: 1.000000  Max: 1.990000
• Mr. Gwido Zlatkes from Harvard University for access to necessary literature

• Mr. Les Cowley for permission to use solar mirage photographs

• Mr. Ctein for permission to use his photography of space shuttle.

2. L.W. Tarasov, ‘Физика в природе’ [Physics of nature], Ed. ‘Просвиищение’, Moscow 1988;

Curvature of light rays

\[ f(x) = \int \frac{n_0}{\sqrt{2kn_0 x + k^2 x^2}} dx \]

Particular solution of this integral:

\[ y = -\frac{n_0}{k} + \frac{m}{k} \cosh\left(\frac{k}{m} x - \text{arcosh}\left(\frac{n_1}{m}\right)\right) \]
Etymologia nazwy

**fatamorgana** miraż złożony, tworzący wielokrotne, zmienne obrazy, pojawiające się (na skutek załamania światła w warstwach powietrza o różnej temperaturze) w Cieśninie Mesyńskiej, nad Jeziorom Genewskim i w Zatoce Toyama w Japonii; omam, złudzenie.

'wróżka Morgana ze śrdw. cyklu rycerskich *Opowieści Okrągłego Stołu* 'króla Brytów, Artura (Artusa), której przypisywano zdolność wywoływania miraży'; *fata* 'czarodziejka', z łac. *fatum*
Light rays path
Shalom
When a light beam is passing through media, which have different refractive index, it refracts.

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\[
\begin{align*}
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    n_2 \sin \alpha_2 &= n_3 \sin \alpha_3 \\
    n_3 \sin \alpha_3 &= \ldots
\end{align*}
\]

General conclusion:

\[ n \sin \alpha = \text{const} \]