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Abstract

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Lens with variable optical characteristics

Research work on creating a lens, the optical power can be changed depending on human needs.

Most people have visual impairments that need to be corrected with surgery or optical devices (glasses and contact lenses). The optical characteristics of the human eye vary depending on age, health, intensity of visual load. We propose to give people the opportunity to smoothly adjust the optical power of the spectacle lens by changing the transparent tubes between the two windows of transparent films. Experimental studies have shown the possibility of adjusting the optical power of the proposed line in a wide range.

Existing devices and materials for changing the optical power of the line are analyzed. The design of a lens with variable optical characteristics is proposed, which is created from two window films, the space between which is filled with liquid. Publicly available materials for the outer shell of the lens and liquid for its filling. The effect of the amount of liquid to be filled on the optical power of the lens was experimentally determined. The formula for experimental finding of focal length of a lens is entered. Novelty is impossible because you can use the lens in another field. For example, in the future it is planned to perform an experiment with a lens system to create, for example, a telescope.

INTRODUCTION

It is difficult to overestimate the role of vision in human life. But the number of people who have certain vision problems is growing. The current generation, unfortunately, has a weak accommodation mechanism. It provides clear vision at different distances, rapid adjustment of the visual system in the distance and near and vice versa. After 45 years of life, the mechanism of accommodation begins to age, and the person again needs to be corrected. Elderly people have to have several glasses with different optical power of lenses: for reading, for watching TV, for use outdoors. Therefore, the creation of lenses, the optical power of which can be changed depending on human needs, is an **urgent** task.

Purpose: to provide a person with comfortable use of a device for vision correction.

To achieve this goal it is necessary to solve the following **research objectives:**

- analyze existing devices and materials to change the optical power of lenses;

consider the physical characteristics of lenses;

- to offer the design of the lens with variable optical characteristics;
- substantiate the materials for the outer shell of the lens and the liquid for its filling;
- determine the effect of the amount of liquid to fill on the optical power of the lens;
- derive a formula for experimentally finding the focal length of the lens.

Object of study: the process of refraction of light in a lens with variable optical characteristics.

Subject of research: the design of the lens, materials for the outer shell of the lens and the liquid for its filling, the relationship between the amount of liquid and the optical power of the lens.

Research methods are based on the study of scientific sources on devices and materials for changing the optical power of lenses, conducting experiments to confirm the feasibility of development.

The practical significance of the work is to create a "liquid" lens with variable optical power.

SECTION 1

PHYSICAL CHARACTERISTICS OF LENSES

1.1. Characteristics of transparent bodies

Transparency of the environment - the physical property of materials to transmit light through. In addition, there is also translucency, a feature of which is the selective absorption of light flux.

The absorption of light is the phenomenon of the loss of energy by a light wave passing through matter through the conversion of wave energy into other forms of energy. The absorption of light can cause deformation because of heating, ionization or excitation of atoms and molecules of matter.

Refraction (Fig. 1.1) is a phenomenon during which there is a change in the direction of propagation of light rays when passing the interface between two media with different optical densities.

Laws of refraction:

- refracted and incident rays, as well as perpendicular to the interface, lowered to the point of impact of the beam, lie in the same plane;

- depending on the optical density of which medium is greater, the angle of incidence may be greater or less than the angle of refraction.

The course of rays in the refraction of light has the property of reversibility: if the point object and its image are swapped, the course of the rays will not change, only their direction will change.

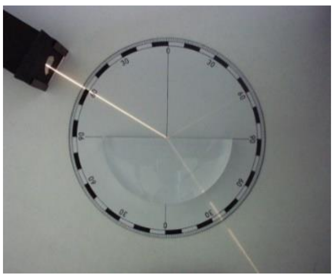


Fig. 1.1 Refraction of light

Source: author’s development

The absolute refractive index, or refractive index, is a numerical value that is specific to a given medium, indicating how many times the speed of light propagation in the medium is less than the speed of light propagation in vacuum. Mostly denoted by n.

The formula for calculating the refractive index:

$$n = \frac{c}{v},$$

where c is the speed of light in vacuum, and v is the phase speed of light in the medium.

In light rays there are the following types of refraction:

- astronomical (curvature of the beam from the luminary by the Earth's atmosphere in the direction of its denser layers, due to which the visible zenith distances always seem smaller than the real ones);

- terrestrial, which occurs in the lower atmosphere and significantly affects the results of high-precision geodetic measurements;

- differential, which is expressed as the difference in the effect of total refraction on the sight lines when measuring distances with double-image rangefinders.

Full reflection of light

We know that in a more optically dense medium, a ray of light forms a smaller angle with a perpendicular drawn to the boundary between the media than a ray that propagates in a less optically dense medium [13].

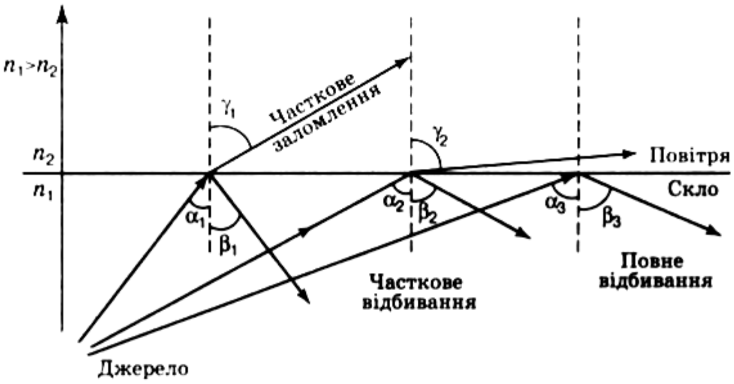


Fig. 1.2 Full reflection of light

Source: author’s development

Therefore, if in this case you increase the angle of incidence, the angle of refraction will increase, and it will always be greater than the angle of incidence. Therefore, at a certain angle of incidence, a refracted beam in a less optically dense medium forms an angle of 90 ° with a perpendicular to the boundary of the separation of media, in other words, it will propagate along the boundary of separation.

If the angle of incidence is further increased, the beam will not fall into the second (less optically dense) medium and will be completely reflected in the first. This phenomenon is called “total reflection of light”, and the angle of incidence at which all light begins to be fully reflected in the first medium is called “the ultimate angle of total reflection” (Fig. 1.2).

Applying the law of refraction, we can find the relationship of the boundary angle of total reflection with the relative refractive index of a more optically dense medium. Indeed, in our case the law of refraction can be written as follows:

$$\frac{\sin a}{\sin y} = n_1 = \frac{1}{n}$$

where n_1 is the relative refractive index of the second (less dense) medium, *n* is the relative refractive index of the first medium. When the angle of incidence is equal to the limit, then the angle of refraction is equal to 90^0. Hence $\sin y = 1$ and

$$\sin a_n = \frac{1}{n}$$

For glass with a refractive index *n* = 1,55, the ultimate angle of total reflection is approximately equal to 40°. The action of optical parts is based on the phenomenon of total reflection and is used to replace mirrors in various optical designs.

Recently, the phenomenon of complete reflection of light has found application in the inventions for the transmission of the image of the object without the help of lenses and mirrors. They are called “light guides”. The fiber consists of many thin (about 20 μm in diameter) filaments about 1 m long each, which are made of glass. These threads are very dense and parallel to each other. At both ends of the fiber the relative position of the ends of the filaments is strictly the same. Each thread is surrounded by a thin shell of glass, which has a lower refractive index than the thread itself.

The law of reflection of light

The angle of incidence of the beam is the angle between the incident beam and perpendicular to the surface that reflects at the point of refraction of the beam (angle α).

The angle of reflection of the beam is the angle between the reflected beam and perpendicular to the surface that reflects at the point of refraction of the beam (angle β).

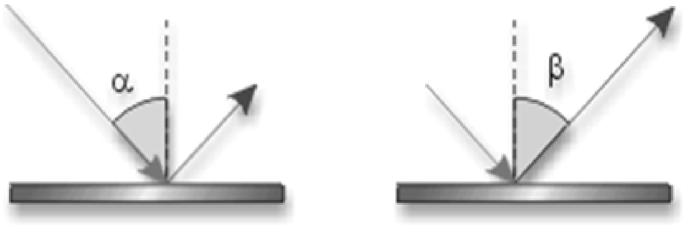


Fig. 1.3 Reflection of light

Source: author's development

When reflecting light, two patterns are always fulfilled:

First: the reflected and incident rays lie in the same plane with the perpendicular to the reflecting surface, which is drawn from the point of incidence of the ray.

Second: the angle of reflection is equal to the angle of incidence [5] (fig. 1.3).

1.2. Lenses and their characteristics

An optical lens is the simplest optical element that is made of a transparent material, bounded by two refractive surfaces that have a common axis or mutually perpendicular axes of symmetry.

Types of lenses. Lenses are divided into thin and thick.

Thin lenses are those whose thickness is small compared to the radius of the spherical surfaces that limit it.

Thin lenses are divided into:

- harvesting plants;
- scattering.

Lenses are distinguished depending on the location of the centers of spherical surfaces and their radius and are divided into:

- biconvex lens;
- flat-convex lens;
- concave-convex lens;
- biconcave lens;
- convex-concave lens;
- scattering meniscus [4].

Thick lenses - when the thickness of the lens cannot be neglected compared to the focal length.

The main parameters of the lens:

- optical center of the lens;
- optical axis of the lens and the main optical axis of the lens;
- the main focus of the lens (real and imaginary) and the focal plane.

The main optical axis of the lens is any imaginary line passing through the centers of the spherical surfaces of the lens.

The optical center of the lens is the point through which the main optical axis passes and intersects the plane of the lens.

The lateral optical axis of the lens is any imaginary line (except the main optical axis of the lens) that passes through the optical center of the lens.

The main focus of the condenser lens is the point where the rays are collected after passing through the condenser lens, which fall on the lens parallel to its main optical axis.

The main focus of the scattering lens is the point where, after passing through the scattering lens, the continuation of the rays incident on the lens parallel to its main optical axis is collected.

The focal length of a lens is the distance from the optical center of the lens to its focus.

The optical power of the lens is the value D inverse to the focal length of the lens:

$$D = \frac{1}{F}.$$

Types of lenses:

- cylindrical;
- Fresnel lens;
- super lens;
- axiconus.

1.3. Characteristics of a thick lens

At school we study the formula of a thin lens, in which we neglect the thickness of the lens itself, but in my work I should take into account the thickness of the lens, because light rays, in addition to refraction, can also be reflected and absorbed. The formula of a thick lens:

$$\frac{n_0}{f} = (n - n_0)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n - n_0)d}{nR_1R_2}\right]; \qquad (1.2)$$

where *f* is the focal length;

n is the refractive index of the lens material;

n_0 is the refractive index of the medium surrounding the lens;

d is the thickness of the lens;

R_1 is the radius of curvature of the surface that is closest to the light source;

R_2 is the radius of curvature of the surface farther from the light source;

R_1- takes a positive value of "+" - if the surface is convex, and a negative "-" if concave [4]

SECTION 2

CREATING A LENS WITH VARIABLE OPTICAL POWER

2.1. Analysis of analogues

At the beginning of the XXI century, there was information about the development of adaptive lenses based on liquid crystals (LC), designed for use in optical systems of telescopes, pulsed lasers, machine vision systems. Pixel Optics has released adaptive Fresnel lenses for bifocal glasses. The optical power of these lenses is changed by applying a control voltage to a thin layer of LC. To increase the resolution of the human eye, it is proposed to use a liquid crystal corrector in the form of an adaptive contact lens implanted in the eye [11]. The use of glasses with adaptive LCD lenses has not yet become widespread due to the high cost.

"Smart" glasses are designed by experts from the University of Utah. Instead of ordinary lenses, flexible "liquid" lenses were installed in the glasses (Fig. 2.1).

A liquid lens is a transparent liquid body that is surrounded by two curved surfaces whose curvature can be changed.In the presented sample, the inner part of the lens is filled with glycerin. The invention works automatically. The thick brackets of these glasses contain rechargeable batteries, the capacity of which is enough for 6 hours of continuous operation of the device. The other bracket contains a microcontroller, power electronic components for drive control and elements of a wireless communication system [1].

In the field of medicine over time, more active use of different variations of liquid lenses. Some of them are places in the eye surgically, the others, as we are used to - as contact lenses [10].

Among the developments there are some inventions of "smart glasses" [6].

Fig. 2.1 Glasses with "liquid" lenses

Source: author’s development

2.2. Different ways to create a liquid lens

2.2.1. Drop on a transparent surface

Probably everyone had to see drops on the windowpane in the rain. Looking at it, you could see an inverted and many times reduced image of what was outside the window.

This phenomenon was taken as the first version of the liquid lens.

The drop is a condenser lens.

For example, you can use it to enlarge the text (Fig. 2.2).

Fig. 2.2 Enlarge the image through a drop

Source: author’s development

As for the types of lenses that can be obtained by this method, it is primarily a condenser lens on the surface (fig. 2.3).

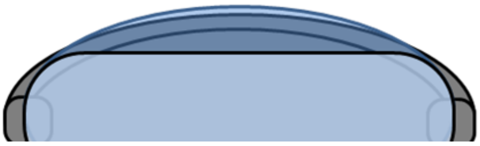


Fig. 2.3 Creating a lens using surface tension

Source: author's development

However, if the drop is placed in a small ring or tube, the diameter of which will be small, then capillary phenomena are formed, and we get a scattering lens (fig. 2.4). The focal length of the drop can be changed by adding the amount of liquid to the drop in the first case, and change the diameter of the tube in the second case.

The optical power of a drop varies from 20 diopters for drops of 8-9 mm and about 200 diopters for droplets (less than 4 mm).

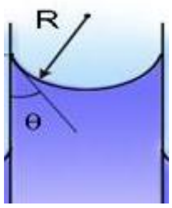


Fig. 2.4 Scheme of the lens in the capillary

Source: author's development

Nevertheless, such a lens is very capricious and has many limitations and disadvantages. For example, a limited radius of curvature of the drop, the drop must be located in a strictly horizontal position, the shape depends on the properties of the surface,etc. [3].

2.2.2. The interface of two immiscible liquids

In fact, it is the same droplet, but not on the glass, but on the liquid. The essence of this model is to add to the vessel with the liquid a drop of another liquid, and the liquids should not be mixed (fig. 2.5). The focal length of the lens changes by increasing or decreasing the amount of liquid in the drop.

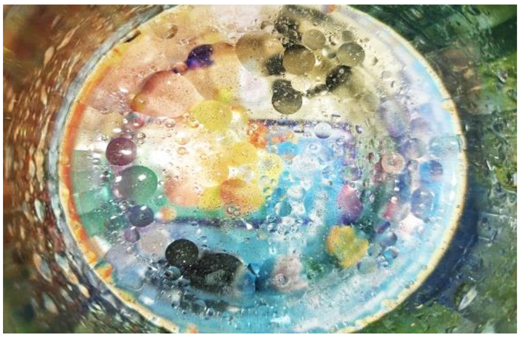


Fig. 2.5 Drops of glycerin in water

Source: author's development

The disadvantages of this model are again the limited radius of curvature of the drop, it works only in a horizontal position, requires no vibration, and so on.

2.2.3. Rotating fluid

The natural way to obtain a lens of this shape is to rotate the container of a cylindrical shape (Fig. 2.6). In the installation offered by us the capacity with liquid is fixed in the bearing. In the process of rotation there are centrifugal forces, which give the fluid a parabolic shape.

Fig. 2.6 The lens is formed by the rotation of the liquid

Source: author's development

Let's understand what types of lenses can be obtained using this model. It is easy to understand that we can change the curvature of only one surface, so the type of lens will depend on the speed of rotation and the shape of the glass.

So, if we take a simple flat-bottomed beaker, we get a scattering flat-concave lens (fig. 2.7). If we make the bottom a little convex inward, then we get a biconcave lens. But making the bottom convex outward, at low speeds, we will get a concave-convex lens. And if, increasing the speed, exceed a certain critical point we get a convex-concave lens.

Fig. 2.7 Changing the shape of the lens depending on the speed of rotation

Source: author’s development

As you can see, this lens is scattering. A parabolic scattering lens is obtained.

As disadvantages it is possible to allocate again a horizontal arrangement, and also absence of necessary vibration.

The peculiarity of this lens is its parabolic shape.

2.2.4. Two elastic films, between which is a liquid

This version of the lens is borrowed from nature: the principle of operation of the lens of the eye was taken as a basis.

It worked almost like glass. It was necessary to pump enough water to avoid aberrations. And the reason was that the design itself was quite flexible, and as a film used the usual film for food. Obviously, it has almost no elasticity.

Therefore, taking into account these two facts, a new model was created.

As a film we used a latex film. This sample could be called a liquid lens, because its focal length varied from 15 to 25 diopters.

The principle of operation of such a liquid lens is simple: two soft elastic films are clamped between plates with round holes. Glycerin is pumped or pumped into the space between the films through a small tube. Glycerin was used because it has a higher refractive index than water, and under the influence of tap water, this film became cloudy.

With this technology you can get two types of lenses:

- biconvex;
- biconcave.

And if you still use a separator between the films, you can get more types of lenses, such as:

- flat-convex;
- concave-convex (positive meniscus);
- flat-concave;
- convex-concave (negative meniscus).

The use of glycerin. It is known that glycerin exists in two types: food (one made from plant or animal raw materials) and inedible "pharmacy" (one made from petroleum products). The first type of glycerin is a safe substance, the second - has a harmful effect on the human body. It should be noted that food glycerin can be heated, and "pharmacy" when heated separately evaporates acrolein (a substance that has pungent odor and causes tearing) [8].

Physical characteristics of glycerin:

- transparent, colorless, dense substance;
- odorless;
- has a sweet taste;
- heavier than water;
- glycerin has the ability to absorb moisture from the air and retain it;
- when heated, glycerin evaporates quickly;
- a solution of glycerin and water in a ratio of 2:1 freezes at a temperature of 46,5°C;
- $n = 1{,}4735$ at a temperature of 20°C.

In our work, we propose to create a lens in which you can change the optical power. The lens, which will consist of two transparent elastic films fixed in a round frame, the space between which will be filled with glycerin, so we can form either a biconvex lens or a biconcave one. In order to change the lens to any other, we propose to establish a barrier between the submitted films, so that by adding or pouring glycerin, we can change the type of lens [2].

2.3. Experimental studies of the lens

Experiment 1: Creating a lens using water.

Objective: to investigate the dependence of optical power on the amount of liquid in a liquid lens.

For the experiment we needed (Appendix A):

- two bases which are made of plexiglass;
- food film;
- syringe;
- a rubber tube that serves as a waterproofing layer installed between the plexiglass blanks;
- meter ruler;
- tripods, with which the current model and ruler are attached.

Conducting an experiment

First, we created a lens by securing the food film between the plates, placing a rubber tube in the layer. Fill the space between the film in the size of $21cm^3$ with water and fix the structure on a tripod. Using a ruler measured the distance from the lens to the image of the object, denoted by f. The arrow was drawn on white paper with a black marker and attached to the flashlight with scotch tape. They shone a flashlight from different distances, looking for a place where the image would be in focus. Measured the indicators on the ruler and denoted by d. Then water was added with a syringe in the size of $1\ \text{cm}^3$. The measured distance between the body and the lens was measured and entered into a table. Using the formula of a thin lens

$$\frac{1}{F} = \frac{1}{d} + \frac{1}{f} \qquad (2.1)$$

measured the focal length of the lens depending on the amount of liquid between the films. Since the lens is condenser and the image is valid, the sign in the formula is "+" everywhere. Perform intermediate transformations of formula (2.1)

$$\frac{1}{F} = \frac{f+d}{df} \tag{2.2}$$

So, we find F by the formula

$$F = \frac{df}{f+d} \tag{2.3}$$

Use the formula to find the optical power of the lens

$$D = \frac{1}{F} \tag{2.4}$$

Substituting formula (2.3) into formula (2.4), we obtain the final formula

$$D = \frac{f+d}{df}$$

From the determined value, a table was compiled and a graph was constructed (Appendix B).

Conclusion: as can be seen from the table and graph, as the volume of water in the space between the films increases, the optical power of the lens increases, and vice versa.

Experiment 2: To study the lens using glycerin, we use the equipment from Experiment 1, replacing the food film with a latex-based material, and instead of water we use glycerin in the amount of $19\ \mathrm{cm}^3$. The data are entered in the table and graphs (Appendix B).

Conclusion: as can be seen from the table and graphs, as the volume of glycerol in the space between the films increases, the focus of the lens decreases and the optical power of the lens increases, and vice versa.

When using the formula of a thin lens, we realized that there is a fairly large error in measurement. Therefore, we decided to find another option to determine the focal length of the lens and its optical power. The solution of the geometric problem will help us in this.

Problem. The distance from the object to the screen $L = 100\ cm$. The lens, which is located between them, gives a clear image of the object on the screen in two positions, the distance between which is $l = 20\ cm$. It is necessary to find the focal length of the lens.

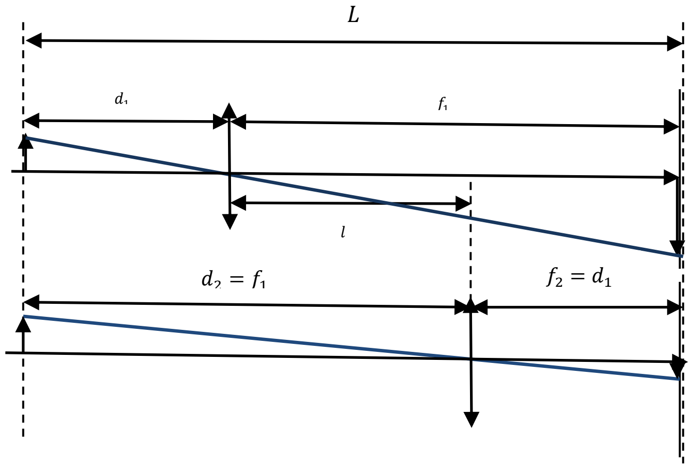


Fig. 2.8 Layout of the lens, screen and object

Source: author's development

To solve the problem, we use the formula of a thin lens

$$\frac{1}{F} = \frac{1}{d_1} + \frac{1}{f_1} \tag{2.5}$$

From (Fig. 2.8) it is obvious

$$L = d_1 + l + d_1 \text{ та } L = f_1 - l + f_1$$

or after elementary transformations

$$d_1 = \frac{L-l}{2} \text{ and } f_1 = \frac{L+l}{2}$$

and substitute in (2.5)

$$\frac{1}{F} = \frac{2}{L-l} + \frac{2}{L+l}$$

Find the focal length of the lens

$$F = \frac{(L-l)(L+l)}{4L}$$

The optical power can be found by the formula (2.4)

$$D = \frac{1}{F}$$

Therefore, using the auxiliary problem, we derived a formula for finding the focal length of the lens. This formula is more accurate because we use a thick lens in which it is difficult to determine the optical center.

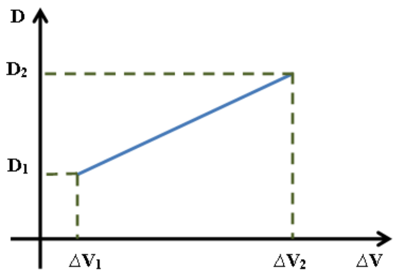
Find the focal length of the lens experimentally.

Place the light source, object, lens and screen on one line. Choose an arbitrary value of L (45; 50; 55 cm), x_1 and x_2. We calculate l and according to the derived formulas we find the focal length and optical power of the lens. Find the value of the focal length as the arithmetic mean of the three measurements.

A table (Appendix D) has been compiled for the initial data, measurement results and calculations.

Then, we added liquid to the lens and moved the lens to a position where there would be a clear image. Let's enter the indicators in the table and determine the dependence of the optical power of the lens on the volume of liquid between the films.

After plotting the dependence of the optical power on the amount of volume, we noticed that the graph is similar to the direct dependence. So we decided to idealize the image and derived formulas for the dependence of volume on optical power and optical power on volume.



$$y = kx + b$$

$$D = k\Delta V + b$$

$$D_1 = k\Delta V_1 + b$$

$$D_2 = k\Delta V_2 + b$$

$$D_2 - D_1 = k\Delta V_2 - k\Delta V_1$$

$$D_2 - D_1 = k(\Delta V_2 - \Delta V_1)$$

$$k = \frac{D_2 - D_1}{\Delta V_2 - \Delta V_1}$$

$$D_1 = \frac{D_2 - D_1}{\Delta V_2 - \Delta V_1}\Delta V_1 + b$$

$$D_1 - \frac{D_2 - D_1}{\Delta V_2 - \Delta V_1}\Delta V_1 = b$$

$$b = \frac{D_1(\Delta V_2 - \Delta V_1) - (D_2 - D_1)\Delta V_1}{\Delta V_2 - \Delta V_1}$$

$$b = \frac{D_1\Delta V_2 - D_1\Delta V_1 - D_2\Delta V_1 + D_1\Delta V_1}{\Delta V_2 - \Delta V_1}$$

$$b = \frac{D_1\Delta V_2 - D_2\Delta V_1}{\Delta V_2 - \Delta V_1}$$

$$\boldsymbol{D} = \frac{\boldsymbol{D_2} - \boldsymbol{D_1}}{\Delta \mathbf{V_2} - \Delta \mathbf{V_1}}\Delta \mathbf{V} + \frac{\boldsymbol{D_1}\Delta \mathbf{V_2} - \boldsymbol{D_2}\Delta \mathbf{V_1}}{\Delta \mathbf{V_2} - \Delta \mathbf{V_1}}$$

$$(\Delta V_2 - \Delta V_1)D = (D_2 - D_1)\Delta V + D_1\Delta V_2 - D_2\Delta V_1$$

$$(D_2 - D_1)\Delta V = (\Delta V_2 - \Delta V_1)D - D_1\Delta V_2 + D_2\Delta V_1$$

$$\Delta \mathbf{V} = \frac{(\Delta \mathbf{V_2} - \Delta \mathbf{V_1})\boldsymbol{D}}{(\boldsymbol{D_2} - \boldsymbol{D_1})} - \frac{\boldsymbol{D_1}\Delta \mathbf{V_2} - \boldsymbol{D_2}\Delta \mathbf{V_1}}{(\boldsymbol{D_2} - \boldsymbol{D_1})}$$

Thus, we derived the formulas for the dependence of the optical power of the lens on the volume of liquid in the lens and the volume of liquid required to change the optical power of the lens.

CONCLUSION

After analyzing the theoretical material associated with "liquid" lenses, we learned that you can create your own lens with variable optical power. Examples of such lenses are a drop of liquid, a liquid in a cylindrical vessel in which a parabolic bend is formed during rotation, the boundary of two immiscible liquids, and two elastic films between which is a liquid.

We have chosen the last option for our work. In our work, we propose to create a lens that will consist of two transparent films, the space between which will be filled with glycerin, so we can form either a biconvex lens or a biconcave one. In order to change the lens to any other, we propose to establish a barrier between the submitted films, so by adding or pouring glycerin, we can change the type of lens.

We experimentally determined the effect of the amount of liquid between the films on the optical power of the lens and derived a formula for experimentally finding the focal length of the lens.

With our development, people will no longer have to change their glasses if their vision has deteriorated or improved, or they need to look at an object near and far, they will be able to adjust the optical power of the lens to their own eye.

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APPENDIXES

Appendix A

Equipment for the experiment

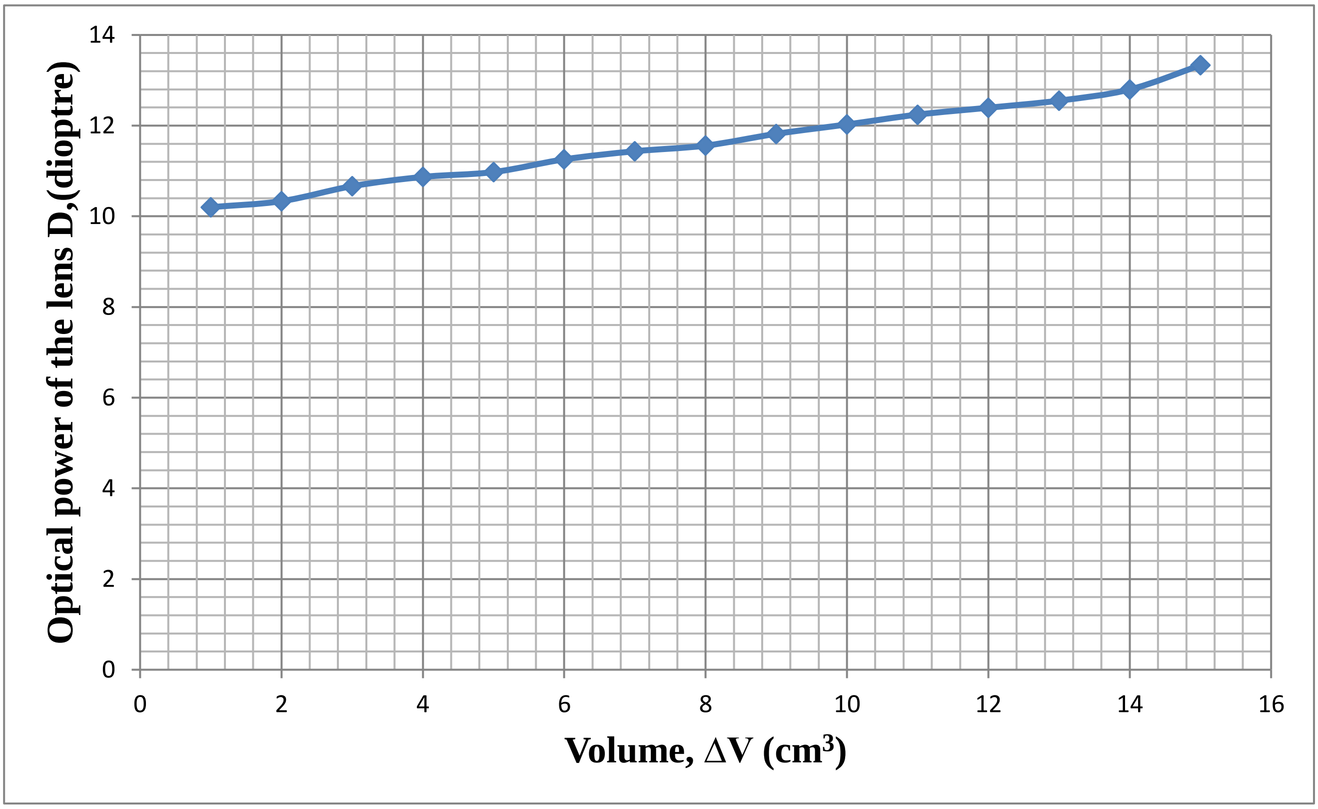
Source: author’s development

Appendix B

Calculations for the lens with water

№	d, m	f, m	F, m	D, dioptre	V, cm^3	ΔV, cm^3
1	0,152	0,276	0,09802	10,2021	21	1
2	0,149	0,276	0,09676	10,3346	22	2
3	0,142	0,276	0,09376	10,6654	23	3
4	0,138	0,276	0,092	10,8696	24	4
5	0,136	0,276	0,09111	10,9761	25	5
6	0,131	0,276	0,08884	11,2568	26	6
7	0,128	0,276	0,08745	11,4357	27	7
8	0,126	0,276	0,08651	11,5597	28	8
9	0,122	0,276	0,0846	11,8199	29	9
10	0,119	0,276	0,08315	12,0265	30	10
11	0,116	0,276	0,08167	12,2439	31	11
12	0,114	0,276	0,08068	12,3951	32	12
13	0,112	0,276	0,07967	12,5518	33	13
14	0,109	0,276	0,07814	12,7975	34	14
15	0,103	0,276	0,07501	13,3319	35	15

Graph of the dependence of the optical power on the change in water volume



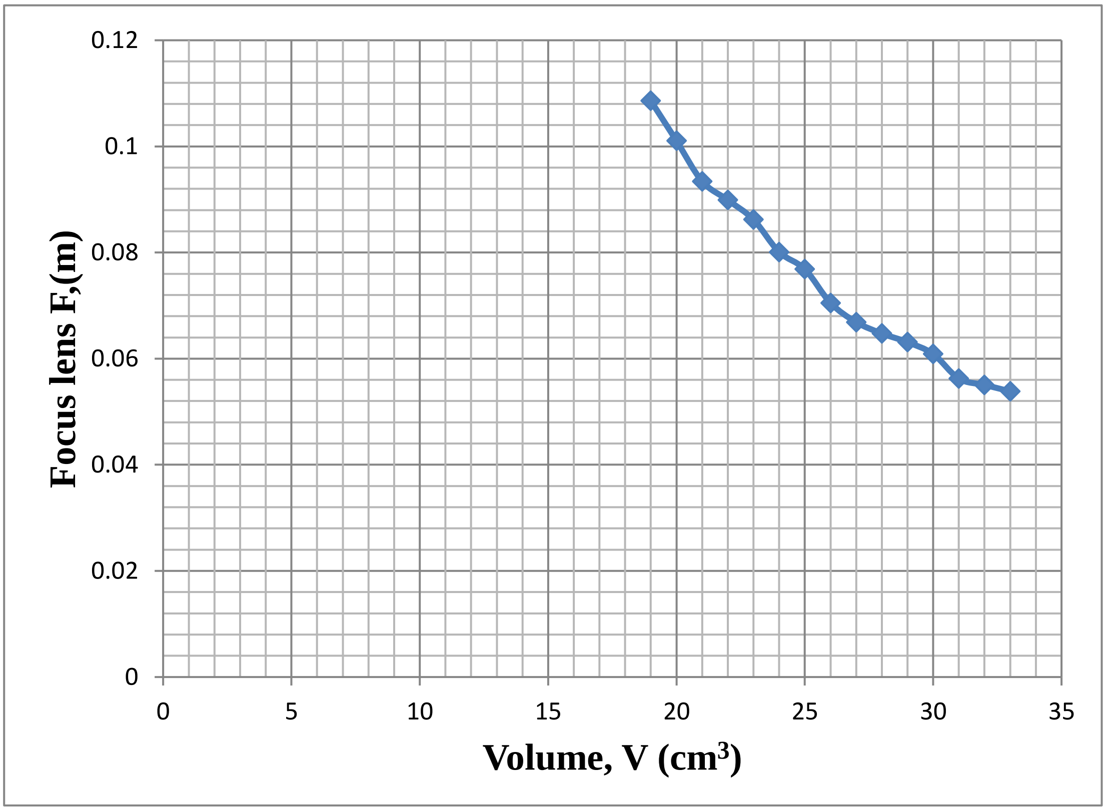
Source: author’s development

Appendix C

Calculations for a lens with glycerin

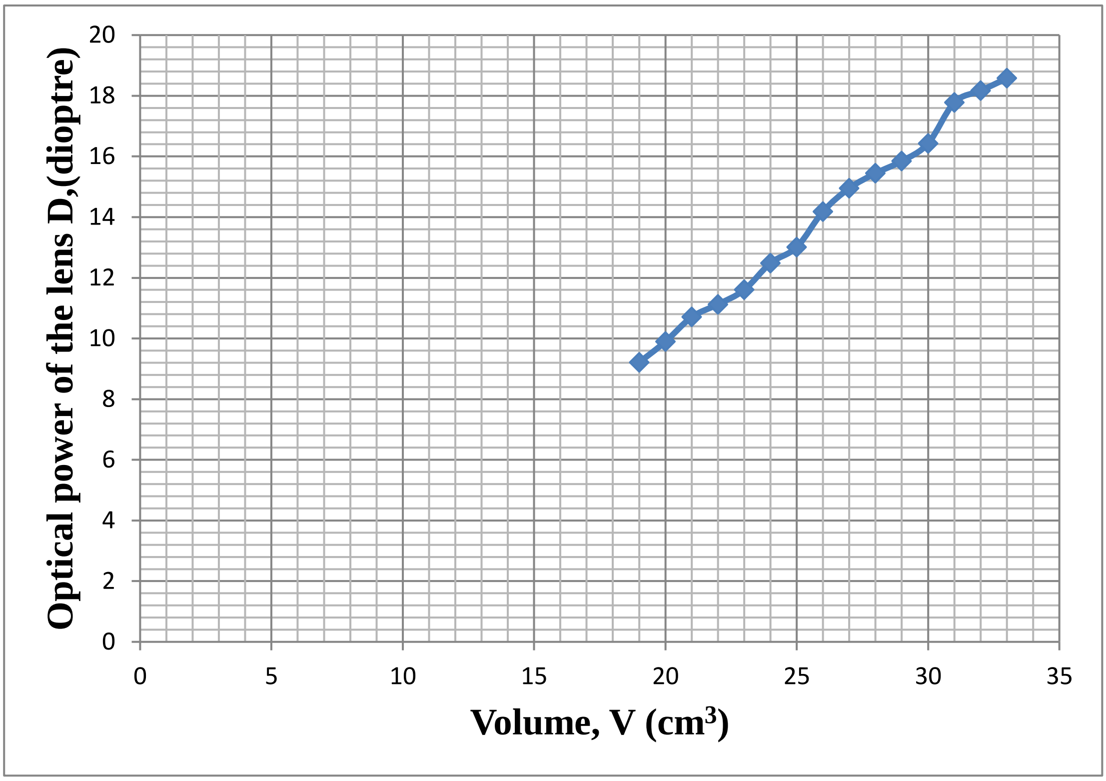
№	d, m	f, m	F, m	D, dioptre	V, cm^3	ΔV, cm^3
1	0,195	0,245	0,10858	9,2098378	19	1
2	0,172	0,245	0,10106	9,8955861	20	2
3	0,151	0,245	0,09342	10,704149	21	3
4	0,142	0,245	0,0899	11,123886	22	4
5	0,133	0,245	0,0862	11,60043	23	5
6	0,119	0,245	0,0801	12,484994	24	6
7	0,112	0,245	0,07686	13,010204	25	7
8	0,099	0,245	0,07051	14,182643	26	8
9	0,092	0,245	0,06688	14,951198	27	9
10	0,088	0,245	0,06474	15,445269	28	10
11	0,085	0,245	0,06311	15,846339	29	11
12	0,081	0,245	0,06087	16,427312	30	12
13	0,073	0,245	0,05624	17,780263	31	13
14	0,071	0,245	0,05505	18,16614	32	14
15	0,069	0,245	0,05384	18,574386	33	15

Graph of the dependence of the focal length on the volume of glycerol

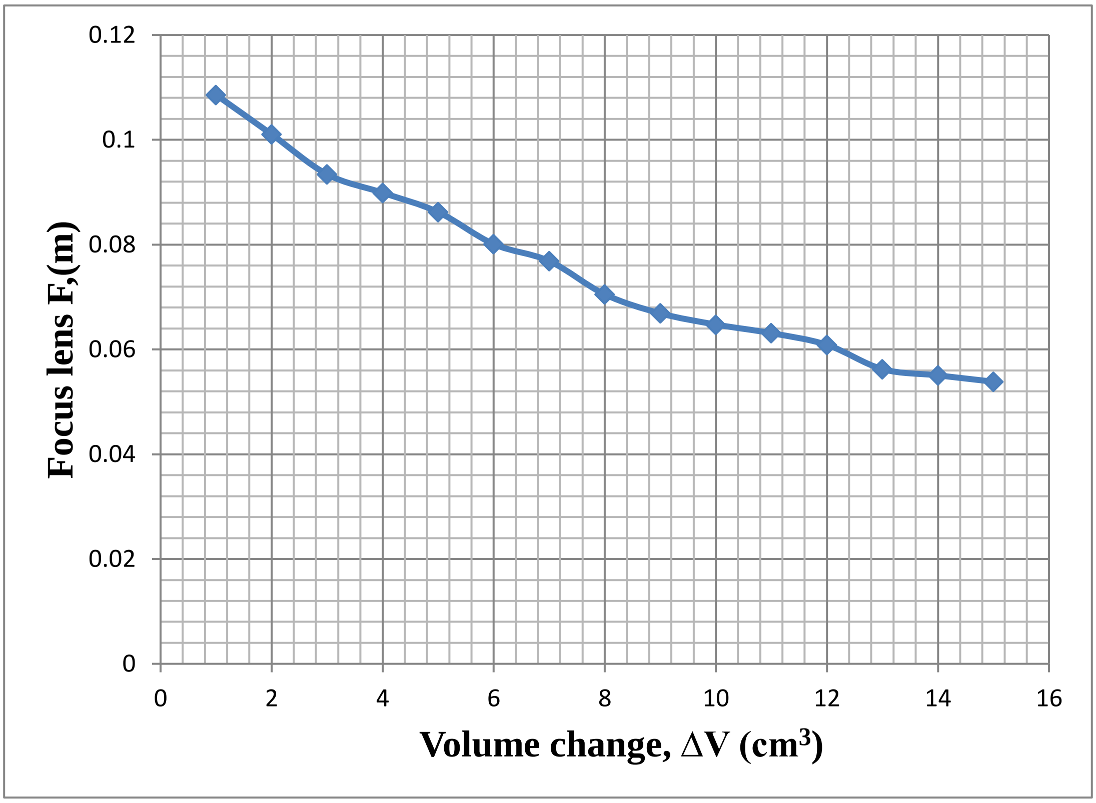


Source: author’s development

Graph of the dependence of the optical power on the volume of glycerol

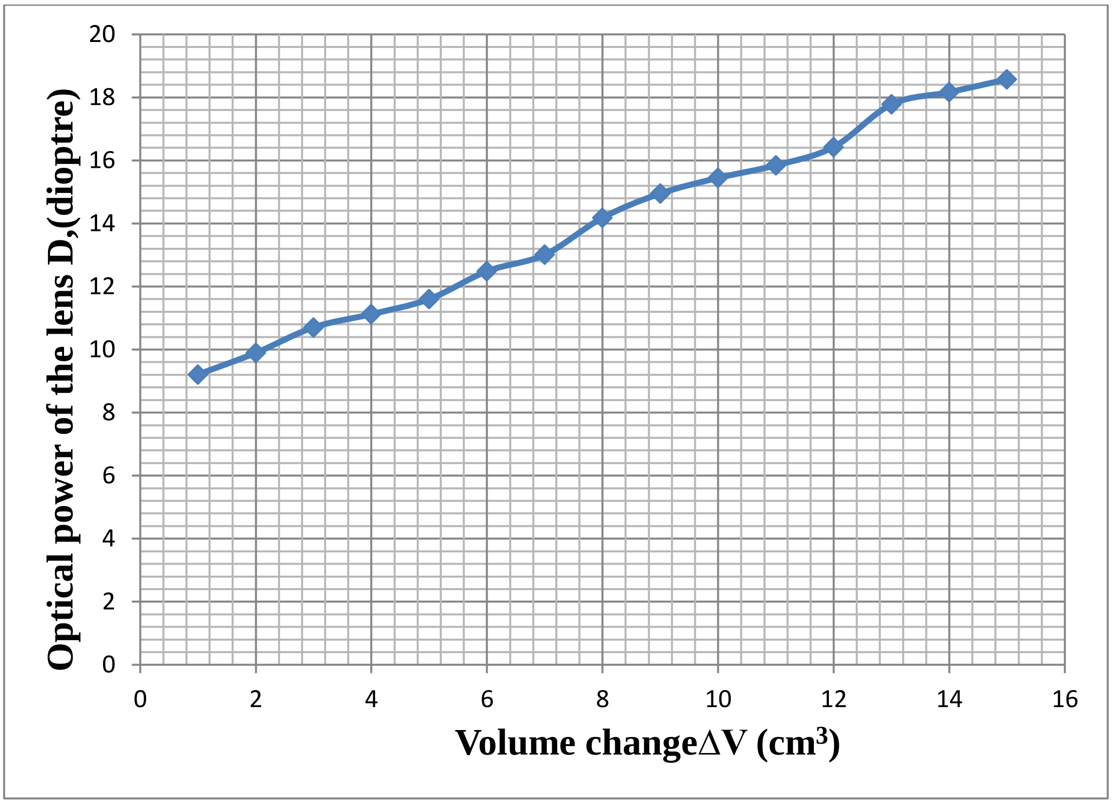


Graph of the dependence of the focal length on the change in the volume of glycerol



Source: author’s development

Graph of the dependence of the optical power on the change in the volume of glycerol



Source: author’s development

Appendix D

Calculations for a lens with glycerin

№	№	L,cm	d_1,cm	f_1,cm	d_2,cm	f_2,cm	l,cm	F	F AM,cm	D	ΔV, cm^3
1	1	50	9	41	40	10	31	7,695	7,770	12,870	0
	2	45	10,4	34,6	35	10	24,6	7,888			
	3	55	8,6	46,4	45	10	36,4	7,727			
2	1	50	9	41	40,4	9,6	31,4	7,570	7,557	13,232	1
	2	45	10,7	34,3	35,7	9,3	25	7,778			
	3	55	8,4	46,6	46	9	37,6	7,324			
3	1	50	8,3	41,7	40,7	9,3	32,4	7,251	7,358	13,590	2
	2	45	9,4	35,6	35,5	9,5	26,1	7,466			
	3	55	8,2	46,8	45,7	9,3	37,5	7,358			
4	1	50	8	42	41,3	8,7	33,3	6,956	7,138	14,009	3
	2	45	8,6	36,4	35,7	9,3	27,1	7,170			
	3	55	8,2	46,8	45,9	9,1	37,7	7,290			
5	1	50	7,7	42,3	41	9	33,3	6,956	7,001	14,285	4
	2	45	8	37	36	9	28	6,894			
	3	55	8,3	46,7	46,4	8,6	38,1	7,152			
6	1	50	7,9	42,1	42	8	34,1	6,686	6,716	14,889	5
	2	45	8	37	36,4	8,6	28,4	6,769			
	3	55	7,4	47,6	46,8	8,2	39,4	6,694			
7	1	50	7,3	47,7	43,4	6,6	36,1	5,984	6,285	15,910	6
	2	45	7,8	37,2	36,8	8,2	29	6,578			
	3	55	8,1	46,9	48,6	6,4	40,5	6,294			
8	1	50	7,2	42,8	42,3	7,7	35,1	6,340	6,307	15,855	7
	2	45	7,6	37,4	37,6	7,4	30	6,250			
	3	55	7,5	47,5	47,9	7,1	40,4	6,331			
9	1	50	6,6	43,4	43,6	6,4	37	5,655	5,960	16,779	8
	2	45	7,4	37,6	37,8	7,2	30,4	6,116			
	3	55	6,4	48,6	47,4	7,6	41	6,109			
10	1	50	6,6	43,4	43,3	6,7	36,7	5,766	5,965	16,765	9
	2	45	7,1	37,9	38	7	30,9	5,946			
	3	55	6,3	48,7	47,1	7,9	40,8	6,183			
11	1	50	6,4	43,6	43,2	6,8	36,8	5,729	5,952	16,802	10
	2	45	6,8	38,2	37,6	7,4	30,8	5,980			
	3	55	6,5	48,5	47,4	7,6	40,9	6,146			
12	1	50	6,3	43,7	43,1	6,9	36,8	5,729	5,931	16,860	11
	2	45	6,8	38,2	38,1	6,9	31,3	5,807			
	3	55	7,1	47,9	47,7	7,6	40,6	6,257			
13	1	50	6,1	43,9	43	7	36,9	5,692	5,734	17,439	12
	2	45	6,7	38,3	38,3	6,7	31,6	5,702			
	3	55	6	49	47,8	7,2	41,8	5,808			
14	1	50	5,7	44,3	42,6	7,4	36,9	5,692	5,635	17,746	13
	2	45	5,9	39,1	37,8	7,2	31,9	5,597			
	3	55	6,1	48,9	48,4	6,6	42,3	5,617			
15	1	50	5,6	44,4	42,9	7,1	37,3	5,544	5,576	17,933	14
	2	45	6,3	38,7	38,6	6,4	32,3	5,454			
	3	55	6,3	48,7	48,3	6,7	42	5,732			
16	1	50	5,2	44,8	43,2	6,8	38	5,280	5,493	18,205	15
	2	45	5,3	39,7	38,7	6,3	33,4	5,052			
	3	55	6,4	48,6	47,3	7,7	40,9	6,146			

Source: author's development

【評語】100040

This work explores liquid lenses with adjustable focal lengths. Note that the idea of liquid lens has been around. Nevertheless, the author has come up with rather detailed discussion regarding the lens' focal lengths. Critically, the aberration of a lens, which determines the imaging quality, is worth further discussion. One of the issues regarding the liquid lens is the effect of gravity, which could generate substantial image aberration and distortion. The effects of other environmental parameters, such as temperature and humidity, may also be discussed. Note that a similar project has been presented in TISF several years ago.