Universal Fedorov Table

Brief manual

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Purpose

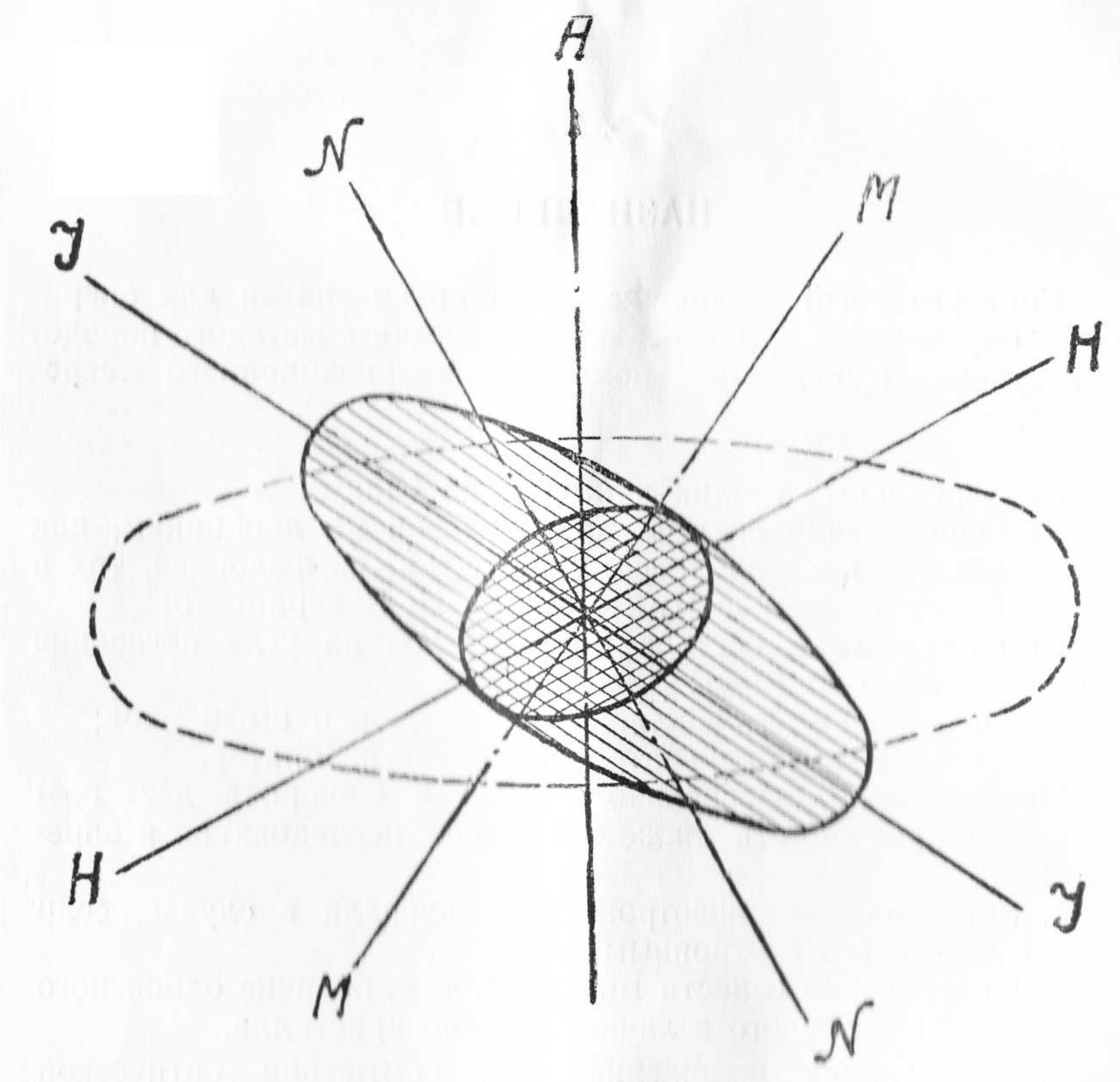
Universal Fedorov table is purposed to determine rock-forming minerals with universal optical method on polarization microscope.

The table is used for:

a) Determining composition of plagioclases by twin crystals with classic theodolite method of E.S.Fedorov and with double theodolite method of A.N.Zavaritski.
b) Determining composition of plagioclases by extinction angle in zone section + (010).
c) Determining of monoclinics, pyroxenes, omfibols.
d) Determining of potassium-sodium feldspars.

Usage of the Fedorov table allows to make following researches and operations:

1. Determining of a mineral anisotropy if you have its isotropy section.
2. Determining of a mineral axiality (to distinguish single-axis mineral from two-axis mineral in any section of the crystal).
3. Determining of the optical indicatrix symmetry axes (and its plane symmetry therefore) and optical axes relatively to a sample.
4. Determining of the optical sign of single-axis mineral in any section.
5. Determining of the optical sign and value of 2v in two-axes minerals either by direct measurement (in section parallel to middle axis of the optical indicatrix N_n) or by Zavaritski method (in section perpendicular to N_n).
6. Determining of main section of the optical indicatrix to determine the mineral birefringence.
7. Determining of positions of faces, cleavage plane and edges relatively to the sample plane.

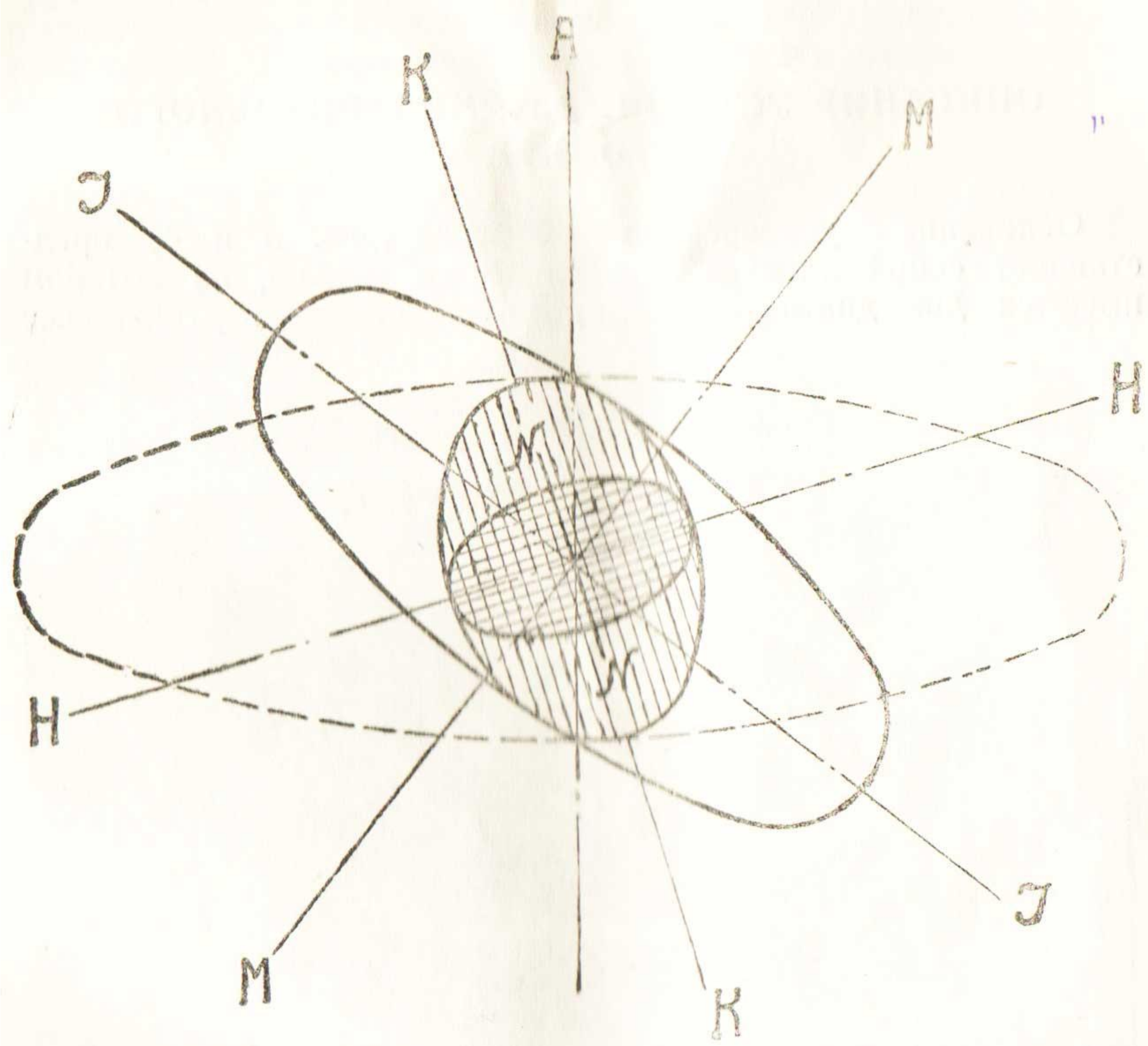


Picture 1. Axes positions on 4-axes Fedorov table.

8. Determining position of the twin axis and plane of the twins fusion relatively to the sample plane.
9. Positioning of the mineral optical indicatrix to align its symmetry axes with the microscope optical axes and with oscillation direction in nicols.
10. Direct determining of the crystallography directions relatively to symmetry axes of the optical indicatrix with double theodolite method.
11. Research of mineral pleochroism.

These determinations can be done for any mineral.

Fedorov tables are manufactured in two versions:



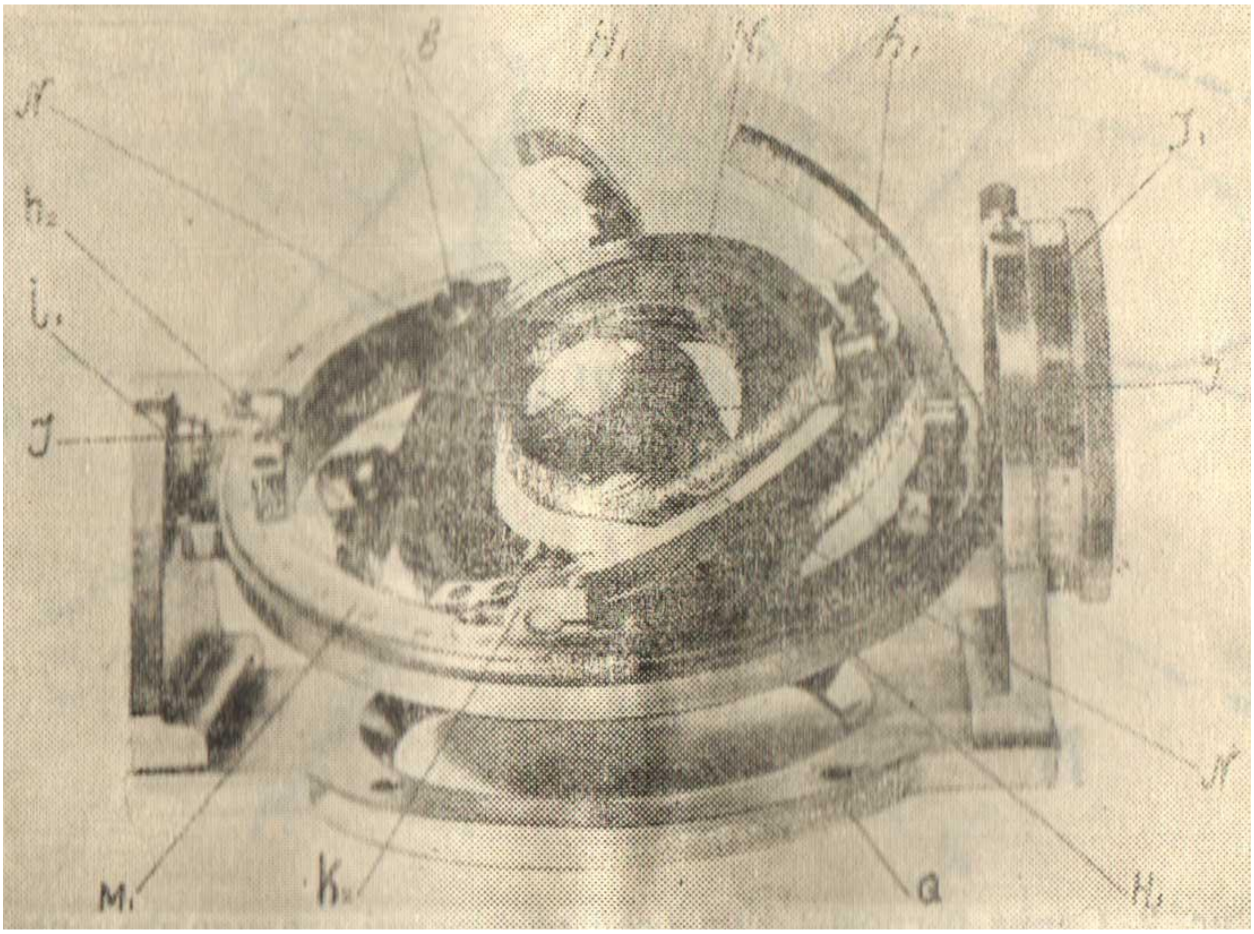
Picture 2. Axes positions on 5-axes Fedorov table.

a) 4-axes universal Fedorov table for classic Fedorov method (Pic.1).
b) 5-axes universal Fedorov table for double theodolite method of Fedorov-Zavaritski.

The 5-axes table can be used as 4-axes one by means of locking *KK* axis with lock screw *k* (Pic.2, 4).

Description of the construction

The base (*a*) of the universal stage (Pic.3, 4) is made as flat metal ring with diametrically positioned vertical stands with wrists (*i*). The wrists hold the axis (*JJ*) that holds the ring (J_2) that has vernier (*j*) and dial (*J*) with 1° scale step, and stop screw (*i*) to lock the axis.

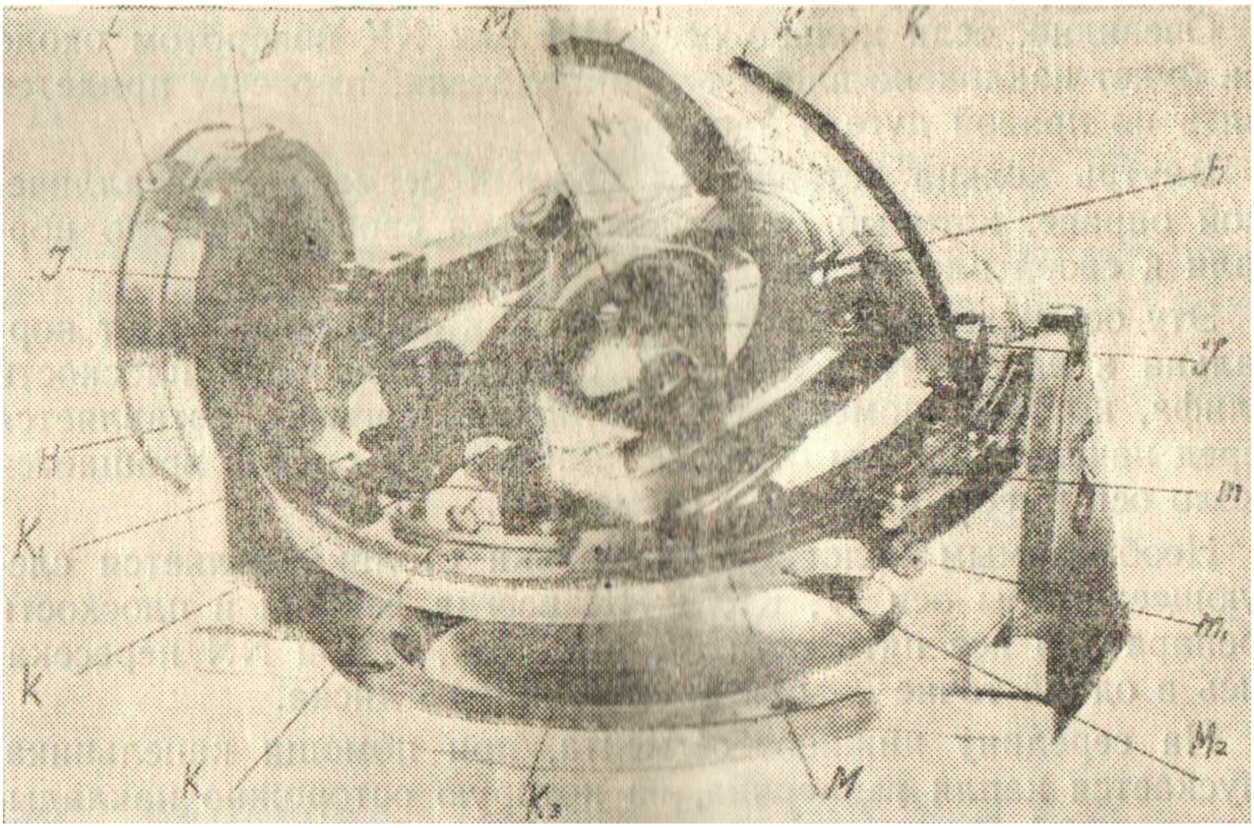


Picture 3. 5-axes Fedorov table (front view).

Fedorov called this axes as fixed axis *JJ*.

The dial of the axis JJ is marked with 1° step in counter-clockwise direction.

The ring M_2 turning with the axis *JJ* holds another ring M_1 that can turn freely in its plane. The ring M_2 is marked from 0 to 360 degrees with 1° scale step.



Picture 4. 5-axes Fedorov table (rear view).

The ring M_1 has two wristsK_2 with the lock screw *k* on one of them. It holds also two arcs k_1 that can be raised to a position perpendicular to the ring M_1 plane.

The acrs k_1 have a scale on one side marked from 0 to 60° with 1° step.

Axis of the ring M_1 (free axis) should be perpendicular to the axis *JJ*. Locking screw m_1 prevents the ring *M* from free rotation. Wrists k_2 of this ring hold axis *KK* that holds the ring k_3 with two wrists h_2 positioned perpendicularly to the *KK* axis. These wrists hold auxiliary axis *HH* and ring N_1 with 360° scale marked with 1° step. The ring N_2 turns on the *NN* axis and can be set into any position.

Skew angle of the ring k_3 is determined by acrs k_1. Skew angle of the ring N_1 is determined by acrs H_1 fixed articulately to the ring k_3. The arcs should be lifted for work. Planes of the axes *KK* and *HH* are always perpendicular to each other.

Bottom segment in metal frame is installed into the inner ring. It can rotate freely around normal to its plane.

This axis is called as axis *NN* since it is always perpendicular to the ring N_1 plane, and, therefore, to the microsection plane that should be put onto bottom segment.

Necessary condition of the Fedorov table adjusting is matching of the axes JJ, KK and HH with the specimen plane, and all five axes JJ, MM, KK, HH and NN shod cross in the center of the glass disc.

Put a glycerin drop with drip into center of the bottom segment. Put the polished specimen onto the prop (cover glass should face top). To do this, place the specimen edge near the drop and lay it onto the drop. That way you'll avoid bubbles in glycerin. If there are bubbles, remove the specimen, add a bit of glycerin, and put the specimen again.

Make sure that there are no bubbles in the glycerin. Then, put a glycerin drop into center of the bottom part of the top segment. Put the top segment over the bottom one, and secure it with screws.

These screws also used to turn the specimen around axes *JJ* and *MM*. Attach the top sphere and loose the screw *i*; turn the specimen around axis JJ by 180°, put a glycerin drop onto bottom part of the disc, and glue the bottom sphere.

So, the polished specimen will have 5 axes of rotation:

1) Around *NN* axis – always normal to the microsection plane and perpendicular to *HH* axis.
2) Around *HH* axis – always in the microsection plane and perpendicular to axes *KK* and *JJ*.
3) Around *KK* axis – in the microsection plane and perpendicular to *HH* axis.
4) Around MM axis – always perpendicular to axes *JJ* and *HH*.
5) Around *JJ* axis – always perpendicular to *MM* axis (optical axis of the microscope).

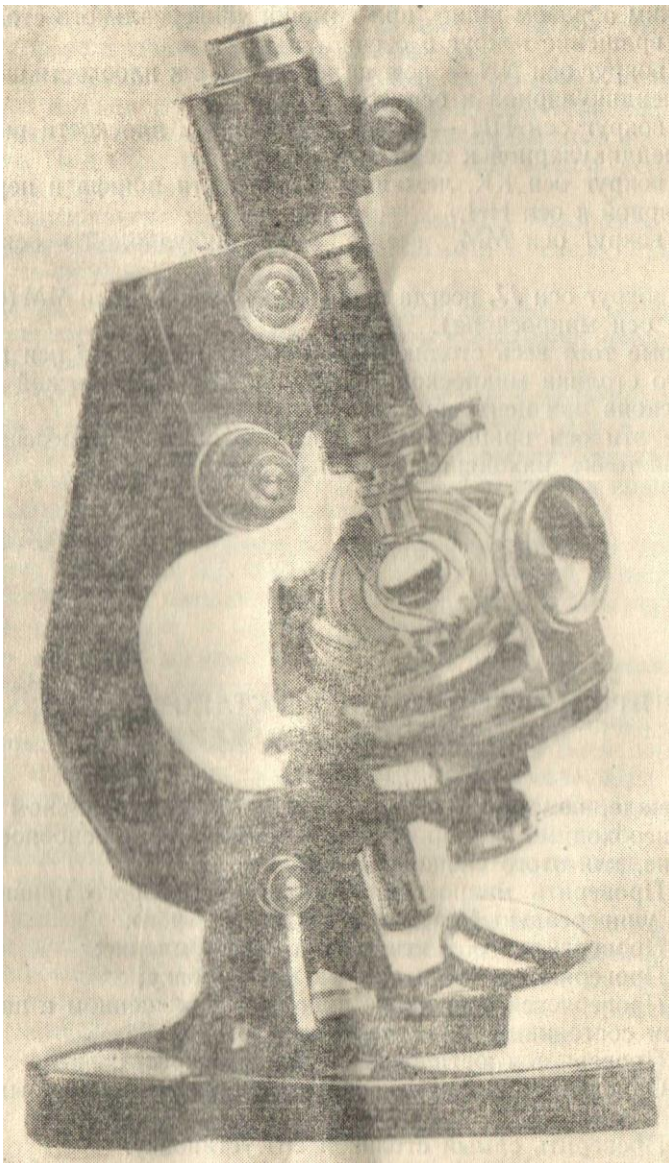
And the whole table can rotate around the microscope optical axis if the table is centered.

All these axes should cross in the same point in the specimen plane.

Checking the table and setting it to base position

Before you begin to work, it is necessary to check the table and set it into base position:

a) Check the microscope that will be used with the table (Picture 5):
1) Check objectives for birefringence;
2) Check centering of the objectives;
3) Check nicols positions in crossed and parallel state.
4) Check an eyepiece crosshair adjustment;
5) Determine oscillation direction passed through polarizer;
b) Check the table itself and its installation.



Picture 5. 5-axes Fedorov table installed onto a microscope.

The Fedorov table should be put onto stage of checked microscope and secured by screws. Base position is as follows:

1) Axes NN and MM aligned with the microscope optical axis (that means that the microscope and the table are centered);
2) Planes of the glass disc and rings M1 and N1 are perpendicular to the microscope optical axis;
3) Index marks of the metal frames a set against zero values of the scales;
4) Axes JJ and KK of the table are perpendicular to the microscope symmetry plane, that means that they are either parallel or perpendicular to the plane of beam oscillation in the polarizer (depending on its position).

Centering of the Fedorov table on the microscope

Install a centering device and the Fedorov table onto the microscope. Glue a microsection to the bottom segment. Align plane of the bottom segment with plane of the ring M_1 by means of the wheel on the bottom side of the frame. Align zero mark of the dial with zero mark of the vernier. Tight locking screws *k*, *h*, *i*. Move a microscope mirror and condenser to achieve bright and even illumination of the field of view in the focused objective (analyzer should be switched off). Move the microsection to put some small but clearly visible point into crosshair center. Secure the table to the stage at any position of *JJ* axis and turn the specimen around *NN* axis observing it into eyepiece. If the point moves in circle, this means that the Fedorov table isn't centered (you should align index mark of the table with index mark of the centering device).

To center the table, turn the microsection till the point is most far from the crosshair. Loose screws (that secures the table and the centering device) a bit and move the point half-way to the crosshair. Tight the screws and rotate the specimen around NN axis again. If the point moves in circle with center in the crosshair, than the table is centered. If center of the circle is shifted, then you need to adjust it again as described above. After you achieved good adjustment, tight screws of the centering device and screws that attaché the table to the microscope. Once centered, the table doesn't need recalibration in the future since the centering device, being adjusted to the given microscope and to the table, keeps the table centered automatically. After the Fedorov table is centered, you should remove the centering device and proceed to work.

Setting the table into base position

Remove an objective from the microscope, loose the screw *i* and turn the table around *JJ* axis till plane of the M_1 ring is approximately parallel to the microscope optical axis. Switch a conoscope lens on (with removed objective) and focus the microscope so that rim of the M_1 ring is clearly visible in the field of view.

Loose the *i* screw and turn the ring around *JJ* axis till the rim get to the center of crosshair. Tight the screw *i*, loose a screw that hold the stage, and turn the whole table around microscope optical axis till the rim is parallel to the horizontal line of the crosshair (or matches it). For more convenient work, position the table so the dial is on your right. Tight the screw. The JJ axis is in work position now. Write down the value on the microscope stage vernier to remember this position and faster positioning of *JJ* axis in the future.

Loose the *i* screw, align zero point of JJ axis with zero point of the table vernier and tight the screw. Loose the screw *h* and turn the disc around HH axis till it gets to vertical position. Tight the screw. Focus to the rim of the disc N_1. Loose the screw m_1 and turn the ring M_1 till the rim of disc h is parallel to the vertical line of the crosshair. Or inline the disc around the *HH* axis till the rim is aligned with the vertical line. Make sure that you turned the disc in right direction, so that mark on the lifted arcs faces toward you for convenient work. Zero mark of the disc *h* on the ring *M* faces you too in such position. Tight the screw m_1 and write down the value on the dial of the ring *M*. This will help you to set the *HH* axis to base position if necessary.

Determining a place for the table axis zero point

Zero point for *JJ* axis is set on the factory. But you may need to check it after transportation of if the table was used by a novice without experience.

Loose the screw *i*, turn the table around *JJ* axis till the center of *HH* axis end is aligned with the crosshair center, and write down a vernier value. Let's name it α. Turn the table in opposite direction till other end of the *HH* axis is centered against crosshair. Write down the value β.

The zero point will be $M_0 = \frac{\propto+\beta}{2} + 180°$

If the dial zero differs from the vernier zero more than be 0.5°, it is necessary to make corresponding adjustments to measurements. For example, α=92°, β=272°.

$$M_0 = (92+272)/2+180 = 362°$$

362° – 360° = 2°, so zero point for *JJ* axis is the second line on the dial.

Therefore, you need to loose the vernier screws I and turn the vernier by 2°. Or just write down this value and use it to adjust measured values.

Adjusting angles due to difference of refraction factors between segments and mineral

As it was said above, essential part of the Fedorov table are two glass spherical segments in metal frames. A glycerin drop is pun onto top surface of the bottom segment, then a microsection is placed over the drop by its cover glass facing top. Another glycerin drop is put onto the specimen, and top segment is placed over it and secured by two spring-loaded screws *b* to the metal ring N_1.

The segments are made that way so they form ideal sphere when they put together with the microsection and glycerin layers. The microsection is positioned in the equatorial plane of this sphere. Bottom segment has pre-determined thickness. That is why the specimen with its object and cover glasses should have specific thickness – not more than 1-1.2 mm. Thickness of the object glass is much greater than of cover glass usually, so it is necessary to place the microsection slide correctly, with the cover glass up.

Glass of the segments, the table disc and microsection glasses have approximately same refraction factor (n_D = 1.516-1.648). Glycerin and Canada balsam have approximately same refraction factors. So, if there is a mineral grain with refraction factor of about 1.5 in the segment center, the whole sphere will be homogenous enough.

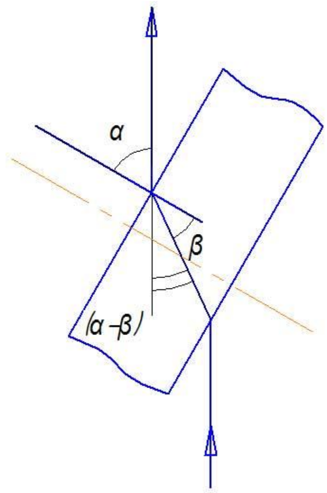
Beams passing through such sphere will not be deflected from original direction at any specimen position since the beam incomes normally (or almost normally) to the spherical surface of the two spheres border at any position of the system. Getting of such system is very important for accurate and quick job. That is why segments with different refraction factors (close to refraction factors of main rock-forming minerals) are manufactured.

Without the segments, only normal to the microsection surface beams wouldn't refracted. If you incline the specimen to any side, refraction could take place, and measured angles could be wrong (greater that true angles in the crystal). With the bottom segment alone, some beans could be lost at all due to inner reflection from the border with air. You may check yourself that without top segment, or with air bubbles in the glycerin, image gets dark even at small angles.

On the other hand, correctly installed specimen and segments allow to observe clear picture up to 50° angles.

This (and pictures below) explains why those segments are so important for the Fedorov table.

Picture 6 shows beams path through inclined plate without a segment. α is visible angle between the beam and normal to the plate corresponding to true angle β in the crystal. Distortion is equal to difference (α–β).



Picture 6. Beam path through a plate without segments.

Picture 7 shows the beam path through a plate enclosed into spherical segments with same refraction factors in case of ideal spherical shape of the system.

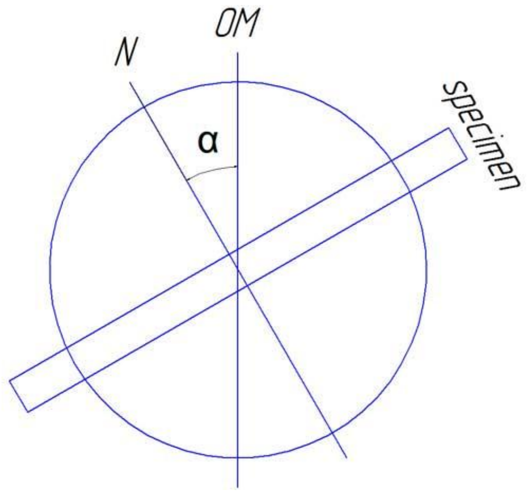
As was said, the spherical segments combined together with the specimen and glycerin layers form an ideal sphere if thickness of the slide (object glass + specimen + Canada balsam + cover glass) is about 1-1.2 mm.

In real life, specimen may have 1.5-2 mm thickness. Let's analyze simple homogenous system with increased thickness of the object glass (that leads to irregular shape of the system sphere).

Picture 8 shows beam path in such system. Let's take a specimen that is thicker than necessary one by value of ε. Center of the top hemisphere will shift relatively to center of the bottom hemisphere by the same value of ε. Beam incoming to the specimen at angle of φ to the plate normal, will came out of the top segment to air with deflection by angle of (*i*–*r*) which is easy to calculate by following equations:

$$n_D = \sin(i)/\sin(r)$$

where n_D is refraction factor of segments.



Picture 7. Beam path through a plate enclosed between segments with same refraction factor as the mineral, if they form ideal spherical shape.

So, sin(i) = nD · sin(r)

From the triangle OO'B:

$$\frac{R}{\sin(\varphi)} = \frac{\varepsilon}{\sin(r)}$$

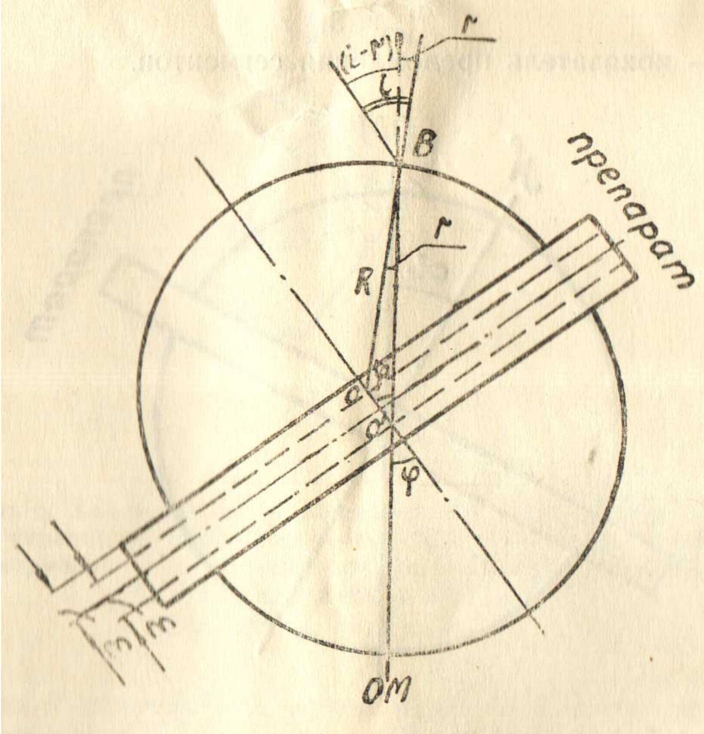
and

$$\sin(r) = \frac{\varepsilon}{R} \cdot \sin(\varphi)$$

where *R* is spherical radius of segments.

You can find some values of (*i*–*r*) calculated for ε=0.5mm and ε=1mm at different R values depending on the specimen inclination angle φ.

The table shows that deflection of the angles (*i*–*r*) (angular error) is less for larger segment radius R and for lesser ε (that means that given specimen thickness is not too much greater than thickness of standard specimen)



Picture 8. Beam path in a system with increased thickness of specimen.

So, it is necessary to have specimens of total thickness not greater than 1.5 mm. Usual thickness of cover glass is 0.1-0.2 mm, specimen thickness is 0.025-0.03 mm. Let's assume that thickness of Canada balsam layer is 0.1 mm on each side. We can calculate thickness of object glass then:

X=1.5 – (0.17 + 0.03 + 0.2) = 1.5 – 0.4 = 1.10 mm. This means that thickness of object glass should be 1-1.2 mm.

Spherical radius of segments	φ	ε = 0.5 mm	ε = 1 mm
R = 5 mm	30°	1°35′	3°10′
	45°	2°14′	4°31′
	60°	2°45′	5°35′
R = 10 mm	30°	0°47′	1°35′
	45°	1°07′	2°14′
	60°	1°22′	2°45′
R = 13.5 mm	30°	0°29′	0°49′
	45°	0°48′	1°54′
	60°	1°04′	2°07′

Let's analyze heterogeneous sphere now, where refraction factor of the mineral differs significantly from refraction factor of the glass spherical segments. In this case, deflection of beams is determined by the refraction equation:

$$\frac{n_D}{n_M} = \frac{\sin(\alpha_M)}{\sin(\alpha_D)}$$

therefore:

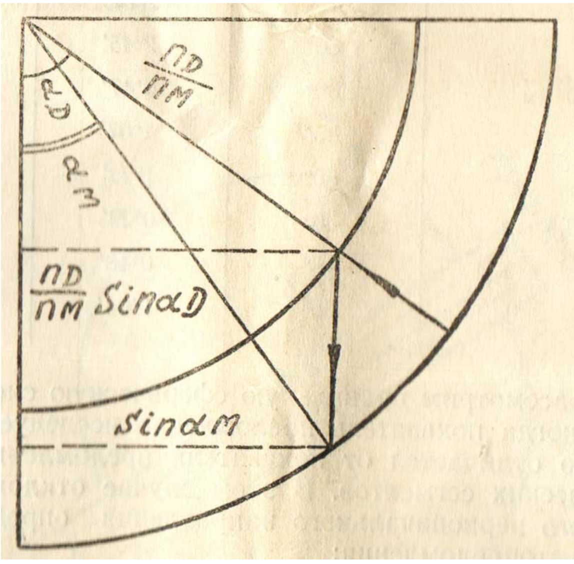
$$\sin(\alpha_M) = \frac{n_D}{n_M} \cdot \sin(\alpha_D)$$

where

α_D – angle in the segment glass
n_D – refraction factor of segments
α_M – angle in the mineral
n_M – refraction factor of the mineral

This equation means that if refraction factor of segments n_D is less than refraction factor of the mineral n_M, then visible angle in the mineral (that we are getting by the table scales readings) will be greater than actual angle α_M (so called true angle in the mineral), and vice versa.

Therefore, if refraction factor of segments significantly differs from refraction factor of the mineral, it is necessary to adjust measured angles when you rotate the table around axes JJ, KK and HH. It is necessary to calculate angle α_n by measure angle α_D knowing refraction factors of segments and the mineral with equation above.

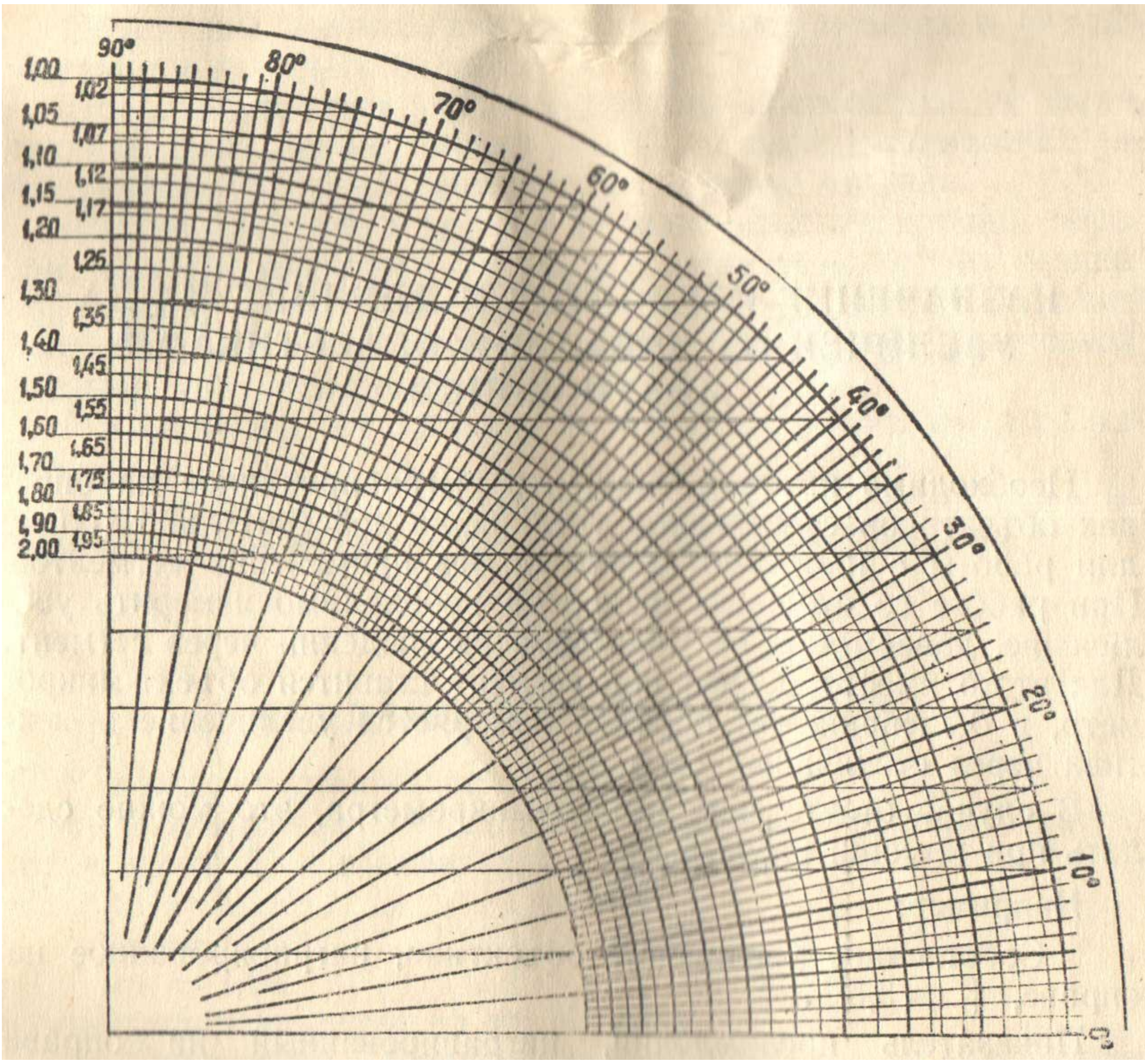


Picture 9. Method of making circular diagram of Fedorov shown on the Picture 10.

Knowing α_D, n_D and n_M, you can easily find necessary angle by means of circular Fedorov diagram shown at Picture 10. Picture 9 explains how to draw it and use it. Outer circle radius is taken as 1. Concentric inner circle has radius of n_D/n_M.

Circular Fedorov's diagram (Picture 10, table 1) has numerous inner circles, and they marked as inversed values (n_M/n_D) for convenience. Let's consider following example to understand this diagram:

Let's take α=60° - angle of specimen inclination around axis JJ or HH, $n_M/n_D = 1.75/1.52 = 1.15$. We start at 60° mark on the outer circle and moving along radius till the 1.15 inner circle. Then we draw horizontal line to the right till the outer circle again, and read value there – 49°. If $n_M < n_D$, then reverse technique should be applied.



Picture 10. Fedorov's circular diagram.

We should start from the angle marked on the outer circle, and move horizontally to the inner circle with n_D/n_M radius. Then we move along radius to the outer circle and read the angle value.

You may skip dividing n_M/n_D. If you take same example, you may start from 60° on the outer circle and move along radius to n_M=1.75 circle. The move horizontally to nD=1.52 circle, and move along radius to the outer circle. We have 49° value again.

Purpose of segments and their affection on the microscope power

It is necessary to keep in mind that objective power marked on it is valid for flat specimen used without segments only. If you use a Fedorov table, it is necessary to measure objective power when it is used with segment. To do this, put an object-micrometer instead of microsection, and measure the power as you usually do.

If you don't have an object-micrometer, you can use calculations. For example:

Objective power marked on it is $\beta=5.5^x$. Refraction factor of the top segment marked on it is n_D=1.64. We need to multiply these values to get actual power of the objective when it is used with this segment:

$$\beta = 5.5 \cdot 1.64 = 9.02^x$$

Storage and maintenance

When you don't use the table, it should be stored in its box.

Optical parts should be kept perfectly clean.

Objectives should be kept in the closed box.

You should protect movable parts of the table from dust since dust makes lube tight and may cause the table break.

To clean optical parts, blow dust off them by means of syringe, bush them with soft brush, and wipe them with clean napkin.

It is forbidden to disassemble the table and objectives.

The box with the table should be stored in dry premise at –4°C to +20°C at normal humidity.

Accessories

Each table comes with three pairs of segments (bottom and top): n_D=1.51, n_D=1.55, n_D=1.64.

Two objectives included:

Table 1

Body mark	Self power	Power with segment	Numeric aperture	Work (free) distance
3.7x0.11	3.7^x	$5\text{-}6^x$	0.11	27 mm
5.5x0.16	5.5^x	$8\text{-}9^x$	0.16	16 mm