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(54) **MAGNETIC ANALYZER FOR RELATIVISTIC CHARGED PARTICLES**

(57) The invention is from the field of physical measuring instruments and nuclear device engineering and can be used to detect relativistic charged particles, to determine their spatial position (angular distribution) and to measure the particle energy spectrum, and can be adapted to study relativistic electron flows in the Earth's radiation belts using space satellites equipped with particle analyzers.

In the proposed relativistic particle analyzers, the uniform magnetic deflecting field is concentrated in the

domain of a right circular cylinder or a semi-cylinder shape, and the focus of analyzer is installed on the side surface of a circular cylinder or in a 90° focal plane.

Circular cylinder surface and 90° plane focusing magnetic relativistic particle analyzers are proposed, characterized by the smaller dimensions and mass, the wider range of measured energies, the higher density of channels leading to the enlarged measurement sensitivity and the better selectivity in particle angular distribution.

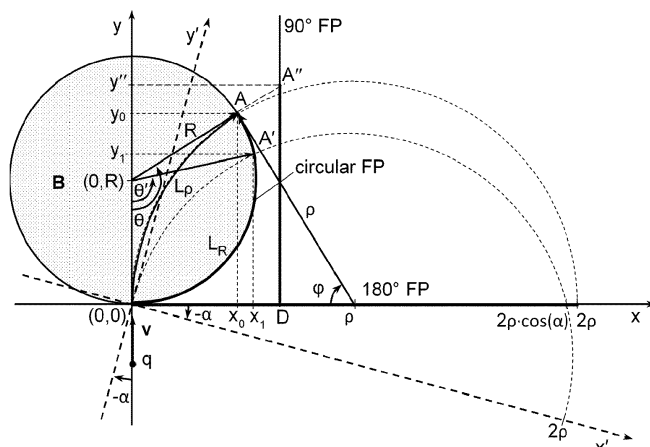


Fig. 5

Description

Technical field

[0001] The invention relates to a field of physical measuring instruments and nuclear device engineering and in particular to devices for detection of relativistic charged particles, determination of the spatial position of the source of electrical particles (particle angular distribution) and measurements of the energy spectrum of particles.

Background art

[0002] Charged particle analyzers are devices used in analytical tools, including most mass spectrometers and electron spectrometers. These devices are instruments that employ electric fields or magnetic fields or both to segregate electrically charged particles in a space in accordance with their kinetic energies or masses (ordinarily, the mass to charge ratio), thereby allowing for selective analysis and detection. Nuclear science was the most prominent field in which mass spectrometry was employed.

[0003] Static magnetic fields historically were the first ones used for energy and mass analysis of charged particles. Despite later appearance of other methods for such analysis magnetic fields are still widely used, for example, for isotopic mass analysis as well as for analysis of energetic charged particles (Mikhail Yavor, "Static Magnetic Charged Particle Analyzers", Advances in Imaging and Electron Physics, Elsevier, Vol. 157, 2009, Pages 69-211). Even though magnetic analyzers are bulky and heavy compared to electrostatic analyzers they are usually used for measuring kinetic energy distributions in high-energy beams in space instruments, in which case achieving the necessary electrostatic field strengths is technically difficult.

[0004] Scientific paper by F. R. Paolini et. al. "Satellite Instrumentation for Charged Particle Measurements II. Magnetic Analyzer for 0.1 to 1.0 MeV Electrons", IEEE Trans. On Nuclear Science, vol. 15, Issue 1, Feb. 1968, pp. 194-213 discloses a 180°-focusing satellite magnetic analyzer (on satellites OV1-9, OV1-13) for the spectroscopy and angular distribution measurements of electrons and is considered to be the closest prior art. The magnetic analyzer comprises: a protective shielding cover with an entrance aperture - an opening through which electrons enter the analyzer; rectangular (1:2) parallelepiped-shaped permanent deflection magnets, provided by a return path (yoke enclosing the pieces of magnet poles) for the magnetic field lines around the shielded volume, thanks to which a uniform magnetic field is created in the void rectangular parallelepiped domain inside the gap between the poles of the magnets perpendicularly to the trajectory of the electron motion; a plane protective screen with eight exit apertures appropriately positioned in the 180° focal plane of the analyzer; a grid of detectors located at the output of each exit aperture outside the permanent magnetic field domain; the magnetic field strength and temperature meters; a calibration particle source and a unit of the analyzer electronics, consisting of separate output channel amplifiers; pulse counters; discriminators etc., for processing the measurement data and preventing the unwanted background counting rate due to extraneous relativistic particles (protons).

[0005] In the closest prior art above, of all the electrons which enter the entrance aperture, essentially only electrons of desired energy ranges reach exit apertures appropriately positioned in the focal plane of the analyzer. The variation in energy ΔE of the electrons falling into the respective energy range depends on angles α and β of the electrons entering the aperture (respectively, in the plane perpendicular to the B field, and in the plane perpendicular to both the latter described plane and the aperture plane), the distance δ from its center, and the channel number N , defined by the radius ρ of the curvature of the circular trajectory of the electron

$$\rho = \frac{E}{q c B} \sqrt{1 + \frac{2 m c^2}{E}}, \quad [1]$$

where E is the kinetic energy of the charged particle; B is the induction of the magnetic field; q is the particle electric charge; m is the particle rest mass; c is the velocity of light in vacuum. The energy variation is defined by the width of the energy bin ΔE (evaluated as a full width at half maximum, FWHM), which is given, according to the common statistical evaluations of measurement precision, by the square root of the sum of the squares of all said individual terms when neglecting their possible correlation. The energy variation ΔE and the deviation of the radius of curvature of the trajectory $\Delta \rho$ in the focal plane are related by

$$\frac{\Delta E}{E} = \frac{\Delta \rho}{\rho} = \alpha^2 + \beta^2 - \frac{\delta}{\rho}. \quad [2]$$

[0006] The width of the energy range of each channel corresponds to the chosen theoretical energy resolution (equal to, for instance, 15% of the FWHM) for electrons entering exactly the center of the entrance aperture perpendicularly to the magnetic field B force lines and the aperture plane (along the aperture axis, $\alpha = \beta = \delta = 0$). The sensitivity of the channel is closely related to $\Delta\rho$, it is the higher for the larger $\Delta\rho$. The energy range of the analyzer depends on the area of the magnetic poles and the magnetic field strength, as well as on the value of $\Delta\rho$. The channel energy values are spaced at equal logarithmic intervals over the range 0.1 to 1.0 MeV.

[0007] Accordingly, one drawback of the closest prior art above is insufficient channel sensitivity (proportional to the value of $\Delta\rho$) in a low-energy region. Another drawback of the prior art is that range of energies measured by the analyzer cannot be increased without increasing the area of the magnet pole tips. Any increase in the dimensions of the magnet poles (at a fixed magnetic field strength) greatly increases the dimensions of the analyzer and, at the same time, its mass, which is completely useless in the case of a satellite instrumentation. Yet another drawback of the prior art relates to the determination of the spatial position (pitch angle analysis) of the source of electrical particles. Determination of the source position (angles of impinging) of relativistic particles is highly dependent on the value of the channel energy (angles β are much larger for the low energy channels where ρ is small due to $\beta = d/(2\rho)$, with d being the distance between the tips of the magnet poles and coinciding with one of the dimensions of the detector, while other dimension of the detector area is defined by $\Delta\rho$). In order to determine the spatial position of the particle source more accurately (by reducing β), the distance d between the tips of the magnet poles must be reduced, which, however, decreases the sensitivity of the analyzer provided that $\Delta\rho$ remains the same.

[0008] The present invention is dedicated to overcoming of the above shortcomings and for producing further advantages over prior art. Compared to the prior art, the invention has smaller dimensions and mass, wider range of measured energies, higher density of channels leading to enlarged measurement sensitivity and the better selectivity in particle angular distribution.

Brief description of the invention

[0009] According to one embodiment of the invention, a device has a uniform magnetic deflecting field concentrated in a void domain between poles of right circular cylindrical magnets of equal diameter with poles at ends of cylinders oriented along a general symmetry axis, in which particle entrance and exit apertures are arranged in a cylindrical shell - right circular hollow cylinder of suitable thickness, placed at the end parts of the poles. The axes of the apertures are directed towards the axis of the cylindrical shell and the cylinder frontal surface of the shell is aligned with the magnetic field B fringe and serves as a focal plane.

[0010] In the second embodiment of the device, differently than in the first embodiment, half of the diametrically divided circular cylindrical magnets are used to create a permanent magnetic field B in a void domain between the poles of the semi-cylinder magnets. A horseshoe-shaped return path yoke enclosing the magnet pole pieces with a width equal to the cylinder diameter is used. Arched side surfaces of the semi-cylinders are oriented towards the horseshoe legs and the particle entrance and exit apertures are located on the side of arched surface of the semi-cylinder magnets.

[0011] In the third embodiment of the device, differently than in the first embodiment, the axis of the entrance aperture of the analyzer is oriented in the direction of the string of the internal cylinder of the cylindrical shell, rotated from the cylinder diameter, traced through the entrance aperture center, to the side, whereof the particle trajectory deviates towards the cylinder center.

[0012] In the fourth embodiment of the device, differently than in the first embodiment, the focus of the analyzer is in the path of the particle trajectory on a plane adjacent to the cylindrical magnetic field domain and oriented in parallel to the axes of the domain and the entrance aperture, arranging the 90° focusing magnetic analyzer.

Brief description of the drawings

[0013] Features of the invention believed to be novel and inventive are set forth with particularity in the appended claims. The invention itself, however, may be best understood by reference to the following detailed description of the invention, which describes exemplary embodiments, given in non-restrictive examples, of the invention, taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows two cross sectional views of first embodiment of the magnetic analyzer in mutually perpendicular planes: a) top view; b) side view.

Fig. 2 shows two cross sectional views of second embodiment of the magnetic analyzer in mutually perpendicular planes a) top view; b) side view.

Fig. 3 shows a cross sectional side view of third embodiment of the magnetic analyzer in mutually perpendicular

planes a) top view; b) side view.

Fig. 4 shows a cross sectional side view of fourth embodiment of the magnetic analyzer in mutually perpendicular planes a) top view; b) side view.

Fig. 5 shows magnetic field and focal planes geometry of first to fourth embodiments.

Fig. 6 shows energy channels arrangement in the focal plane of the magnetic analyzer of the prior art and four embodiments of the device design.

[0014] Preferred embodiments of the invention will be described herein below with reference to the drawings.

Detailed description of the invention

[0015] It should be understood that numerous specific details are presented in order to provide a complete and comprehensible description of the invention embodiment. However, the person skilled in art will understand that the embodiment examples do not limit the application of the invention which can be implemented without these specific instructions. Well-known methods, procedures and components have not been described in detail for the embodiment to avoid misleading. Furthermore, this description should not be considered to be constraining the invention to given embodiment examples but only as one of possible implementations of the invention.

[0016] The first to fourth embodiments of the magnetic analyzer of the present invention are shown in the figures Fig. 1 - Fig. 4 and comprises: a protective shielding cover (1); an entrance aperture (2); optionally a particle collimator (2.1); deflection permanent magnets (3) having N and S poles; a domain (3.1) of a uniform magnetic field; a yoke (4) enclosing the permanent magnets (3); a protective detector holder (5) of non-magnetic material where the frontal surface of the protective detector holder (5) is a focal plane (5.1); exit apertures (6.1 ÷ 6. N); a grid of detectors (7.1 ÷ 7. N); a magnetic field strength sensor (8); a temperature sensor (9).

[0017] Illustrations of the magnetic field and focal planes geometry, and operation principles are given in Fig. 5, where: (x, y, z) and (x', y', z') are Cartesian coordinate systems; R - magnet cylinder radius; $(0, R)$ are coordinates of the magnetic cylinder center; B - induction of a permanent magnetic field; v - charged particle velocity directed along the y axis; q - electric charge of the charged particle; $x_0, x_1, y_0, y_1, y_2, D$ - distances from the beginning $(0, 0)$ of the Cartesian coordinate system, which coincides with the center of the entrance aperture (2) shown in the Fig. 1 - Fig. 4; L_p - length of the charged particle trajectory (2.2), in the magnetic field; L_R - focal distance from the beginning of Cartesian coordinate system on the cylindrical focal surface, a circular focal plane (5.1, circular FP); ρ - radius of curvature of the charged particle trajectory (2.2); α - angle of incidence of the charged particles with respect to the y coordinate; φ - angular length of the circular trajectory (L_p) of the charged particle; θ, θ' - angular focal distances on the cylindrical surface (5.1, circular FP); A, A', A'' - the points of intersection of the charged particle trajectory (L_p) and the focal plane (5.1, circular FP), or (5.1, 90° FP), respectively.

[0018] Comparison of energy channels arrangement in the focal plane of the prior art and all embodiments of the invention are given in Fig. 6, where: PrA - energy channels arrangement (distance 2ρ) in the focal plane (180° FP) of the magnetic analyzer of the prior art; I, II - energy channels arrangement (distance L_R) in the focal plane (circular FP) of the magnetic analyzer of the first and the second embodiment; III - energy channels arrangement (distance L_R) in the focal plane (circular FP) of the magnetic analyzer of the third embodiment; IV - energy channels arrangement (distance y'') in the focal plane (90° FP) of the magnetic analyzer of the fourth embodiment.

[0019] According to the first embodiment of the invention and Fig. 1a and Fig. 1b, the magnetic analyzer for relativistic charged particles comprises: a protective shielding cover (1) with an entrance aperture (2); a collimator (2.1) of relativistic particles installed in front of the entrance aperture (2) which is optional; internally to the protective shielding cover (1) mounted permanent cylindrical magnets (3) with poles N, S enclosed by a magnetic pole yoke (4), by which a uniform magnetic field B is created in the void cylindrical domain (3.1) inside the gap between the poles (N, S) of the magnets (3); a protective detector holder (5) of non-magnetic material in a shape of cylindrical hollow shell with entrance (2) and exit apertures (6.1 ÷ 6. N) for relativistic charged particles, placed coaxially with the cylindrical magnets (3) at the end parts of the poles (N, S) where the inner surface of the cylindrical shell is a frontal surface being aligned with the magnetic field domain (3.1) fringe serves as the focal plane (FP) of the device, where the axes of the apertures (2, 6.1 ÷ 6. N) are directed towards the general axis of the cylinders; a grid of detectors (7.1 ÷ 7. N) located at the output of each exit aperture (6.1 ÷ 6. N) outside the magnetic field domain (3.1) of permanent magnets (3); a magnetic field strength sensor (8); a temperature sensor (9); a calibration particle source (not shown) and an analyzer electronics unit (not shown), consisting of separate channel amplifiers, pulse counters, discriminators etc., for processing of the measurement data and preventing the unwanted background counting rate due to extraneous relativistic particles. The dotted arrow line (2.2) denotes a trajectory of a charged particle.

[0020] According to the second embodiment of the invention and Fig. 2a and Fig. 2b, the magnetic analyzer for relativistic charged particles is made analogously to the construction of the first embodiment and as depicted in Fig. 1a and Fig. 1b, except that the permanent magnets (3) are semi-cylindrical, twice as light and are arranged with a horseshoe-shaped return path yoke (4) enclosing the semi-cylinder magnet pole pieces (3) of the width equal to the semi-cylinder diameter. Arched side surfaces of the semi-cylinder magnets (3) are oriented towards the horseshoe legs (4.1), and the charged particle entrance aperture (2) and exit apertures (6.1÷6.N) are located on the side of arched surface of the semi-cylinder magnets (3).

[0021] According to the third embodiment of the invention and Fig. 3 the magnetic analyzer for relativistic charged particles is made analogously to the construction of the first embodiment and as depicted in Fig. 1a and Fig. 1b, except that the axis of the entrance aperture (2) of the analyzer is oriented in the direction of the protective detector holder (5) of non-magnetic material in a shape of the cylindrical shell string at an acute angle to the internal cylinder diameter traced through the entrance aperture (2) center, and the axis of the entrance aperture (2) is directed into that side from the diameter whereof the trajectory (2.2) of the particle deviates towards the center of the protective detector holder (5) of non-magnetic material in a shape of the cylindrical shell.

[0022] According to the fourth embodiment of the invention and Fig. 4, the magnetic analyzer for relativistic charged particles is made analogously to the construction of the first embodiment and as depicted in Fig. 1a and Fig. 1b, except that the protective detector holder (5) of non-magnetic material is in a shape of a straight shielding bar with its frontal surface being arranged on a 90° focusing plane (5.1) outside the permanent magnetic field domain (3.1), oriented in parallel with the axes of the magnetic cylinder domain (3.1) and the entrance aperture (2), where the bar has built-in exit apertures (6.1÷6.N) along the trajectory (2.2) of the particle.

[0023] The magnetic analyzer for relativistic charged particles of the first embodiment operates as follows: A relativistic particle with charge q , mass m and moment p (or kinetic energy E) passing through the particle collimator (2.1) enters the inside of the analyzer through the entrance aperture (2), where a circular homogeneous permanent magnetic field domain (3.1) of induction B oriented perpendicularly to the particle velocity v is formed (Fig. 5). The trajectory (2.2) of the charged particle in the magnetic field is a circular arc which radius of curvature ρ is related to the kinetic energy E of the particle according to formula [1]. The arc length L_ρ along which the particle travels in the magnetic field within the cylindrical domain (3.1) between the poles (N, S) of the magnets (3) of radius R , after it enters the analyzer exactly through the aperture (2) center and perpendicularly to the aperture plane ($\alpha = \beta = \delta = 0$), is calculated by the formula

$$L_\rho = \rho \cdot \cos^{-1} \left(1 - \frac{2R^2}{R^2 + \rho^2} \right). \quad [3]$$

[0024] After passing through the magnetic field B , the particle enters one of the analyzer channels (1÷N) through the exit aperture (6.1÷6.N), where the average kinetic energy value of the recorded particle (at certain fixed values of q , B and R) is determined by the angle θ (Fig. 5):

$$\theta = \cos^{-1} \left(- \frac{\left(\frac{E}{c}\right)^2 + 2mE - (qBR)^2}{\left(\frac{E}{c}\right)^2 + 2mE + (qBR)^2} \right). \quad [4]$$

[0025] The energy variation of the particles in the respective energy bin ΔE depends on the impinging angles α and β relative to the entrance aperture (2) plane (respectively, in the plane perpendicular to the magnetic field B lines and in the plane perpendicular to said plane and in parallel with the aperture (2) axis. It also varies with the distance δ from the aperture (2) center, and the channel number N , characterized by the kinetic energy E of the particle (or the radius ρ of curvature of the trajectory (2.2)). The energy variation ΔE and the distance deviation $\Delta L_R = R \cdot \Delta \theta$ (where $\Delta \theta$ is the angular deviation) on the focal surface are related

$$\frac{\Delta E}{E} = \frac{\Delta L_R}{L_R} = \frac{\Delta \theta(\alpha)}{\theta} + \frac{\Delta \theta(\beta)}{\theta} + \frac{\Delta \theta(\delta)}{\theta}, \quad [5]$$

in which, respectively:

$$\frac{\Delta\theta(\alpha)}{\theta} = \frac{\cos^{-1}\left(1 - \frac{2\rho^2 \cdot (\cos \alpha)^2}{R^2 - R\rho \cdot \sin \alpha + \rho^2}\right)}{\cos^{-1}\frac{R^2 - \rho^2}{R^2 + \rho^2}} - 1; \quad [5a]$$

$$\frac{\Delta\theta(\beta)}{\theta} = \frac{\cos^{-1}\left(1 - \frac{4\rho^2 \cdot (\cos \beta)^2}{2R^2 + \rho^2 \cdot \cos 2\beta + \rho^2}\right)}{\cos^{-1}\frac{R^2 - \rho^2}{R^2 + \rho^2}} - 1; \quad [5b]$$

$$\frac{\Delta\theta(\delta)}{\theta} = \frac{\cos^{-1}\left(\frac{2R^3 + R\delta^2 + 2\rho R\delta - (\rho + \delta) \cdot \sqrt{4R^2\rho^2 - 4\rho^2\delta^2 - 4\rho\delta^3 - \delta^4}}{2R(R^2 + \rho^2 + 2\rho\delta + \delta^2)}\right)}{\cos^{-1}\frac{R^2 - \rho^2}{R^2 + \rho^2}} - 1. \quad [5c]$$

[0026] The discrete energy values ($E_1 \div E_N$) ascribed to the analyzer channels ($1 \div N$) are arranged according to the desired distribution (usually spaced at equal logarithmic intervals) and the angular positions ($\theta_1 \div \theta_N$) of the respective channels ($1 \div N$) in the focal plane (5.1) are evaluated using the formula [4]. The middle of the energy range, $E_{N/2}$, is chosen from the condition $\rho(E_{N/2}) = R$ using formula [1]. The ΔE_i values, related to the respective values of α , β and δ , are calculated, according to the common statistical evaluation of measurement precision, as the square root of the sum of the squares of the individual terms with a set of all the mentioned deviations [5a $\div$ 5c].

[0027] The angle β depends on the distance d between the poles (N , S) of the magnets (3), and it is chosen to be small enough in order to minimize the effects risen from the magnetic field distortion at the edges of the magnetic field domain (3.1) but it is compatible with the dimensions of the detector used, and it is defined for each channel as follows:

$$\beta_i = \tan^{-1} \frac{d}{2\rho_i \cdot \cos^{-1}\left(\frac{\rho_i^2 - R^2}{\rho_i^2 + R^2}\right)}. \quad [6]$$

[0028] The width of the rectangular entrance aperture (2) is also taken to be of the same size as the distance d between the poles (N , S) of the magnets (3), and the length $2 \cdot \delta$, together with the value of the angle α , is chosen so that $\Delta E/E$ (Eq. 5) is, e.g., 15%. The aperture (2) can also be of circular shape with radius δ .

[0029] The magnetic analyzer is then calibrated using the reference particle sources:

- a) energy calibration, i.e. the average energy value E_i ascribed to each channel ($1 \div N$) and the width of energy variation ΔE_i are determined;
- b) the detection efficiency η_i of each channel ($1 \div N$) is measured, including the signal-to-noise ratio of the amplifiers, as well as the gain and discriminator thresholds;
- c) channel ($1 \div N$) pulse counters are calibrated;
- d) the input aperture (2) parameters are measured: the aperture areas A_i , angular dependence $(A_\Omega)_i$ of an aperture, and the spatial viewing angles Ω_i .

[0030] During calibration, the ambient temperature is controlled, and the magnetic field induction B values are corrected (ρ is assumed to be linearly dependent on B). For the higher accuracy, calibrations are performed under rough vacuum conditions.

[0031] The final channel pulse counter coefficient is calculated using the relationship:

$$R_i = j_0(E_i) [(A_\Omega)_i \Delta E_i \eta_i], \quad [7]$$

where $j_0(E_i)$ is the number of particles about E_i ($\text{cm}^2 \cdot \text{ster} \cdot \text{eV}$)⁻¹ and η_i is the detection efficiency.

[0032] The magnetic analyzer for relativistic charged particles of the second embodiment operates in the same way as the magnetic analyzer of the first embodiment.

[0033] The magnetic analyzer for relativistic charged particles of the third embodiment functions similarly to the first embodiment, except that the discrete angular positions θ of the apertures (6.1 $\div$ 6.N) of the output channels ($1 \div N$) in the focal plane (5.1) of the analyzer (Fig. 5) are calculated using the formula

$$\theta' = \cos^{-1} \left[- \frac{\left[\left(\frac{E}{c} \right)^2 + 2mE \right] \cdot \cos(2\alpha) + 2(qBR) \cdot \sin(\alpha) \cdot \sqrt{\left(\frac{E}{c} \right)^2 + 2mE - (qBR)^2}}{\left(\frac{E}{c} \right)^2 + 2mE - 2(qBR) \cdot \sin(\alpha) \cdot \sqrt{\left(\frac{E}{c} \right)^2 + 2mE + (qBR)^2}} \right], \quad 0 < \theta' < 2\pi. \quad [8]$$

$$\theta' = 2\pi - \theta', \quad \frac{E \cdot \sin(\alpha)}{q c B} \sqrt{1 + \frac{2mc^2}{E}} > R.$$

[0034] Here α denotes the angle between the axis of the entrance aperture (2) and the diameter of the cylindrical magnetic domain (3.1) traced through the center of the entrance aperture (2). The magnetic analyzer for relativistic charged particles of the fourth embodiment (Fig. 4) works similarly to the first embodiment, only the discrete positions of the channel exit apertures in the focal plane (5.1) are calculated according to the formula

$$y_i'' = R - D \cdot \cot(\theta_i). \quad [9]$$

[0035] Here, D denotes the distance of the focal plane (90° FP) from the center of the entrance aperture (0,0) (Fig. 5).

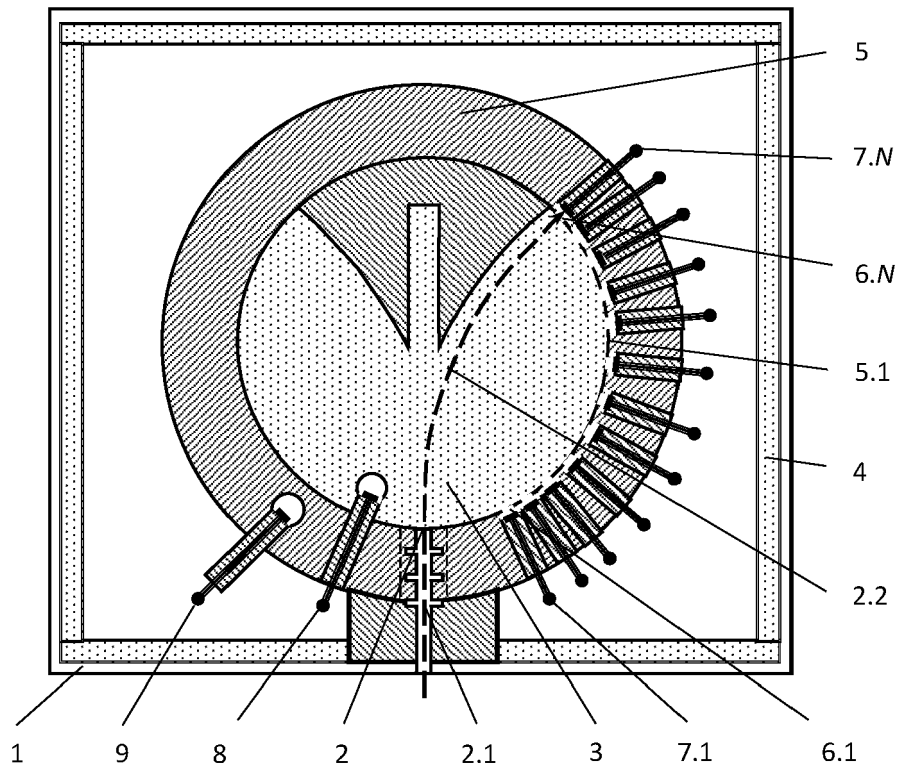
[0036] Fig. 6 shows a comparison of the prior art and the proposed embodiments of the magnetic analyzer, showing the arrangement of the exit apertures (6.1÷6.N) on the focal plane (5.1) of the analyzer. The parameters used in the calculations have been chosen as follows: $d = 1[\text{cm}]$; $B = 0.1 [\text{T}]$; $q = -e[\text{C}]$; $S = \pi R^2 = 50 [\text{cm}^2]$; $D - R = 0.3 [\text{cm}]$; $\alpha = 0$ for the first, second and forth embodiment and $\alpha = 45^\circ$ for the third embodiment of the invention. All other parameters, employed for comparison of the prior art and the proposed embodiments, except magnets and focal surfaces, coincided. The range of measured energies reached for all the proposed embodiment versions is larger than that of the prior art. The channel (1÷N) sensors (7.1÷7.N) located on the focal plane (5.1) are distributed essentially uniformly and has small dependency on the energy of the channel number (1÷N). In the case of the second and third embodiments, the surface areas of the magnetic poles (N, S) (an area ascribed to the magnetic field flux) are twice smaller dimensions (and, thereby, the twice less mass of the magnets as well). In the case of the fourth embodiment, the apertures (6.1÷6.N) are arranged at relatively large distances which makes it possible either to reach the significantly higher sensitivity, as it is proportional to the detector area, or to increase the spectral resolution of the analyzer under the same other conditions. In the case of the first, second and third embodiments, the particle trajectories (2.2), ascribed to different channels (1÷N), are essentially short and uniform over their length, decreasing the spatial viewing angles dependency on the channel energy. Due to the higher sensitivity of the analyzer (longer distances between channel exit apertures (6.1÷6.N), an additional particle collimator (2.1) can be installed, which can increase the resolution of the spatial position of the particle source.

[0037] Although numerous characteristics and advantages together with structural details and features have been listed in the present description of the invention, the description is provided as an example fulfilment of the invention. Without departing from the principles of the invention, there may be changes in the details, especially in the form, size and layout, in accordance with most widely understood meanings of the concepts and definitions used in claims.

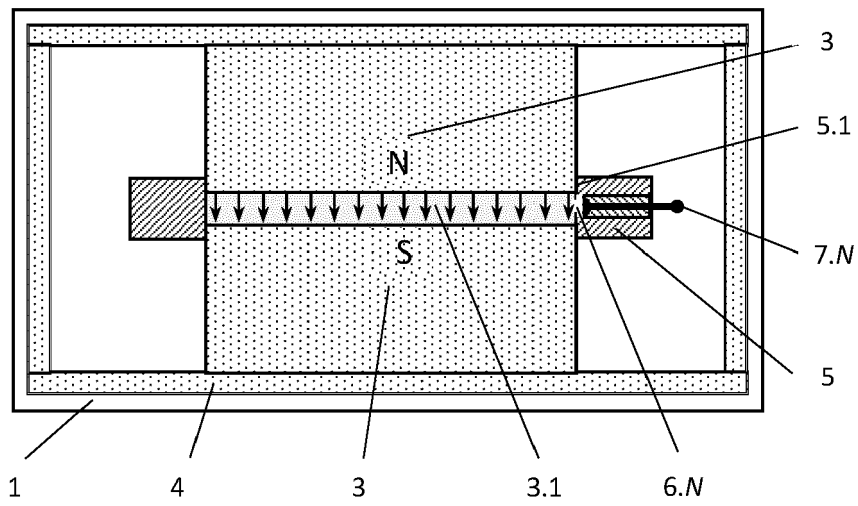
Claims

1. Magnetic analyzer for relativistic charged particles comprising a protective shielding cover (1), an entrance aperture (2), deflection permanent magnets (3), and a magnetic pole yoke (4) for enclosing poles of the permanent magnets (3) and directing magnetic field flux around the shielded volume, a magnetic field domain (3.1) inside a gap between poles of the magnets (3) comprising a uniform perpendicular to the trajectory of the relativistic charged particle motion magnetic field B, a protective detector holder (5) of non-magnetic material, a focal plane (5.1), exit apertures (6.1÷6.N) for relativistic charged particles and a grid of detectors (7.1÷7.N) wherein each detector (7.1÷7.N) is located at the output of each exit aperture (6.1÷6.N) outside the magnetic field domain (3.1), **characterized in that** the relativistic charged particle exit apertures (6.1÷6.N) are arranged within the non-magnetic protective detector holder (5) placed adjacent to the magnetic field domain (3.1) and the frontal surface of the protective holder is aligned with the focal plane (5.1) of the device.
2. Magnetic analyzer according to claim 1 **characterized in that** the magnetic field domain (3.1) of the uniform magnetic field B has a shape of right circular cylinder and the non-magnetic protective detector holder (5) has a form of the hollow cylindrical shell being placed coaxially with the cylindrical magnets (3) where inner surface of the hollow cylindrical shell is aligned with the magnetic field domain fringe and is a focal plane (5.1) where the axes of the apertures (2, 6.1÷6.N) are directed towards the general axis of the cylinders.

3. Magnetic analyzer according to claim 2 **characterized in that** the magnetic field domain (3.1) of the uniform magnetic field B has a shape of right circular semi-cylinder and the particle entrance aperture (2) and exit apertures (6.1 ÷ 6.N) are located on the side of arched surface of the semi-cylinder magnets (3).
- 5 4. Magnetic analyzer according to claim 3 **characterized in that** the return path for magnetic field flux is provided by a yoke (4) having a shape of a horseshoe and enclosing semi-cylinder permanent magnets (3) where arched surfaces of the magnets (3) are oriented towards ends of the horseshoe legs (4.1) having width equal to the diameter of the semi-cylinder magnets (3).
- 10 5. Magnetic analyzer according to claim 2 **characterized in that** the axis of the entrance aperture (2) of the analyzer is oriented in the direction of the string of the internal cylinder of the protective detector holder (5) of non-magnetic material in a shape of a hollow cylindrical shell, rotated from the cylinder diameter, traced through the entrance aperture (2) center, to the side, whereof the particle trajectory deviates towards the cylinder center and exit apertures (6.1 ÷ 6.N) are directed along the trajectory (2.2) of the particle.
- 15 6. Magnetic analyzer according to claim 2 **characterized in that** the protective detector holder (5) of non-magnetic material is a straight bar arranged on a 90° focusing plane (5.1) outside the permanent magnetic field domain (3.1), oriented in parallel with the axes of the cylindrical magnetic field domain (3.1) and the entrance aperture (2), with built-in exit apertures (6.1 ÷ 6.N) along the trajectory (2.2) of the particle.
- 20 7. Magnetic analyzer according to any previous claim **characterized in that** a collimator (2.1) of relativistic particles is installed in front of the entrance aperture (2).



a)



b)

Fig. 1

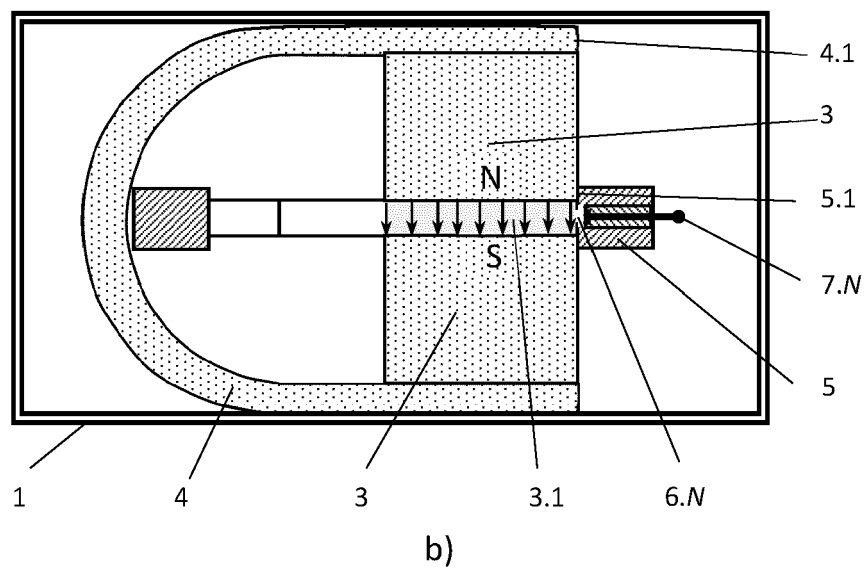
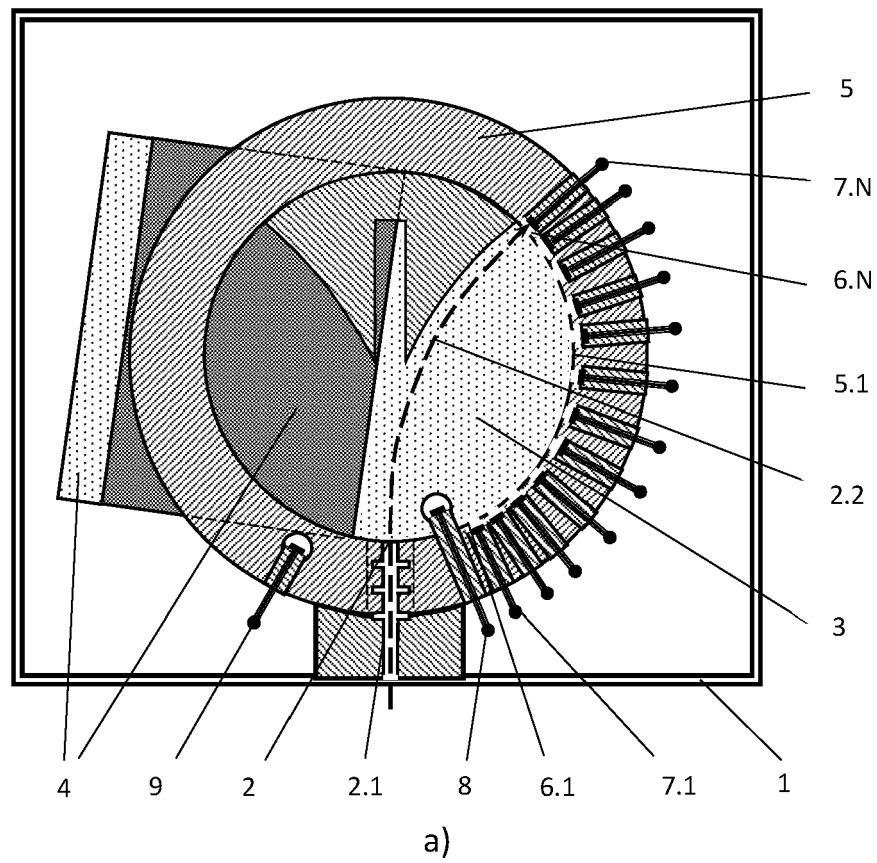


Fig. 2

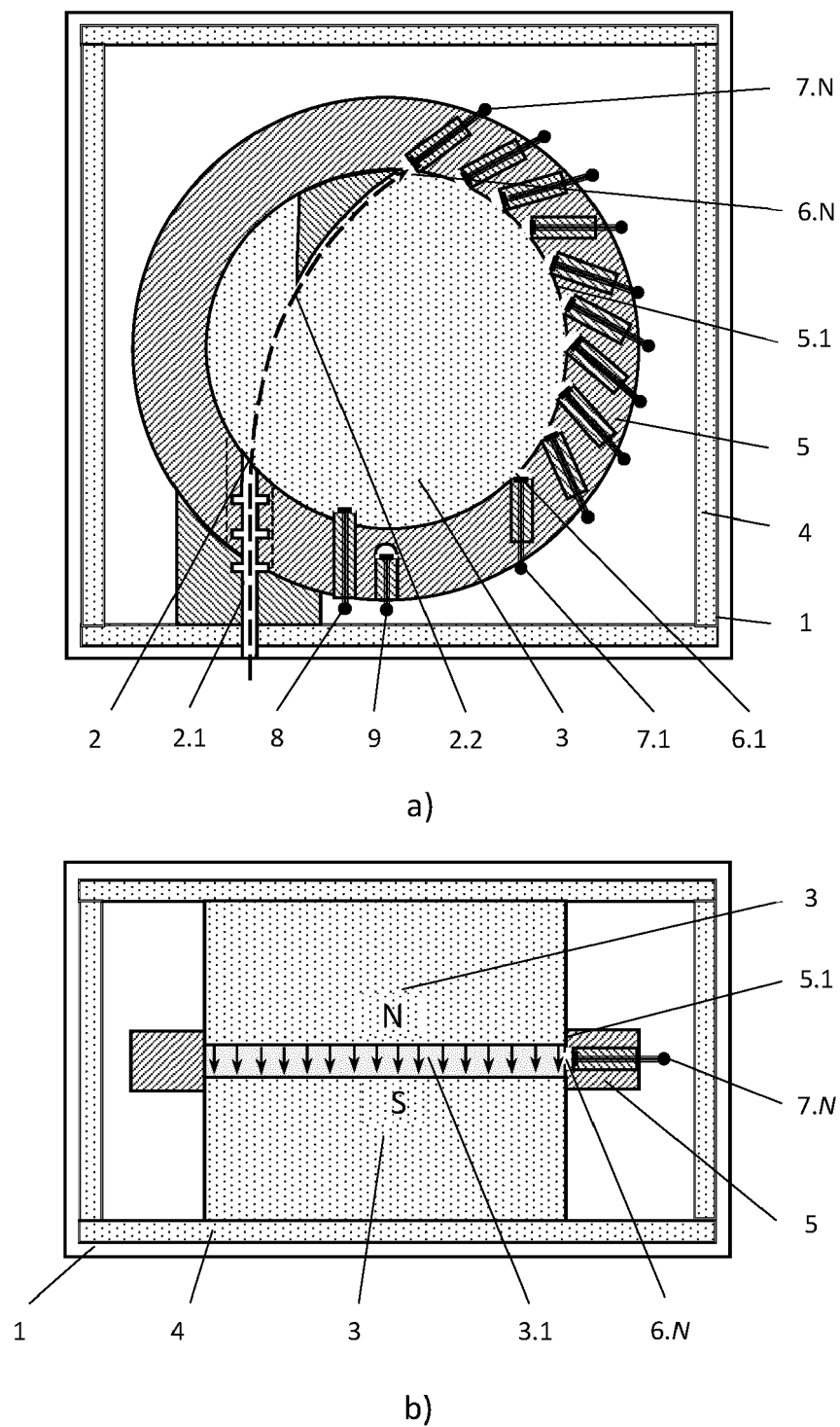
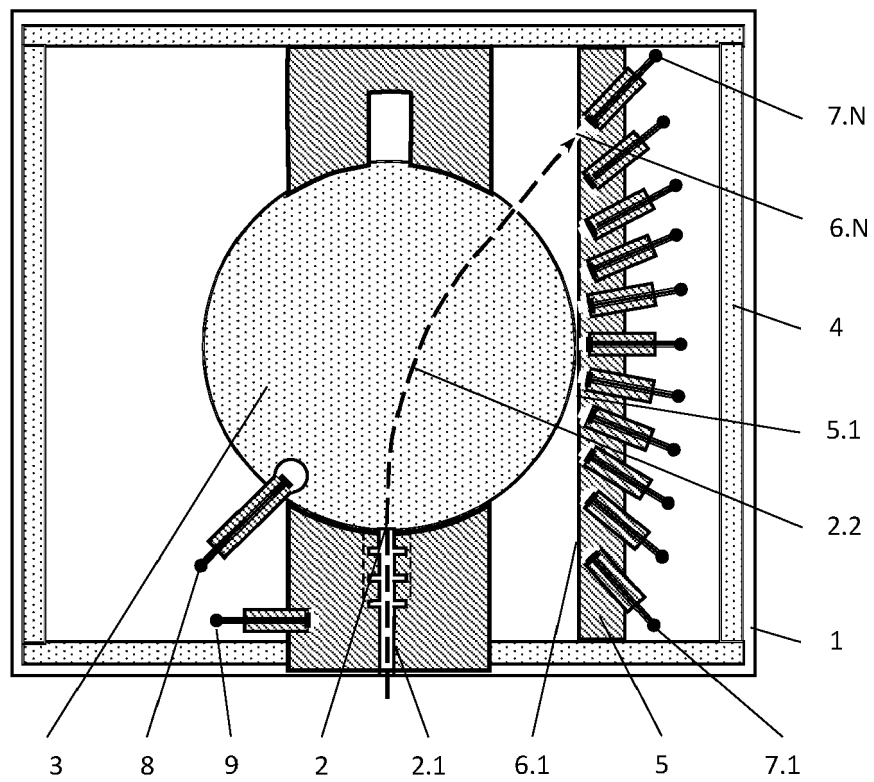
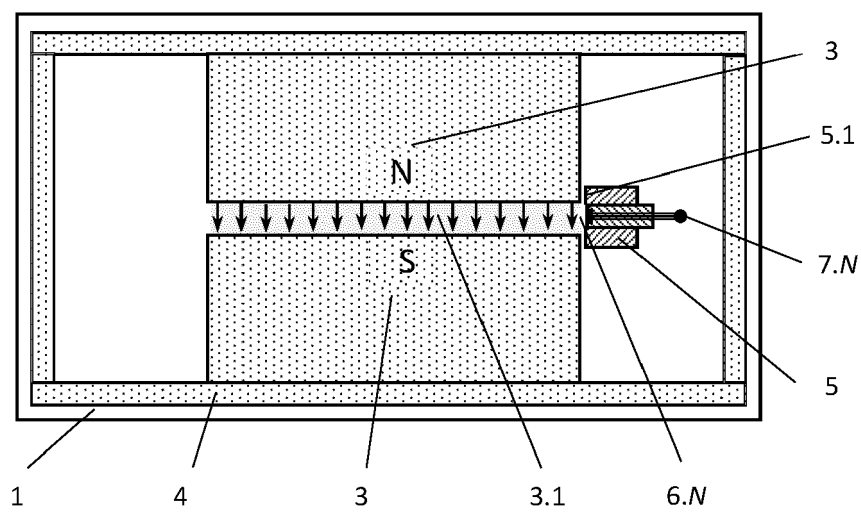


Fig. 3



a)



b)

Fig. 4

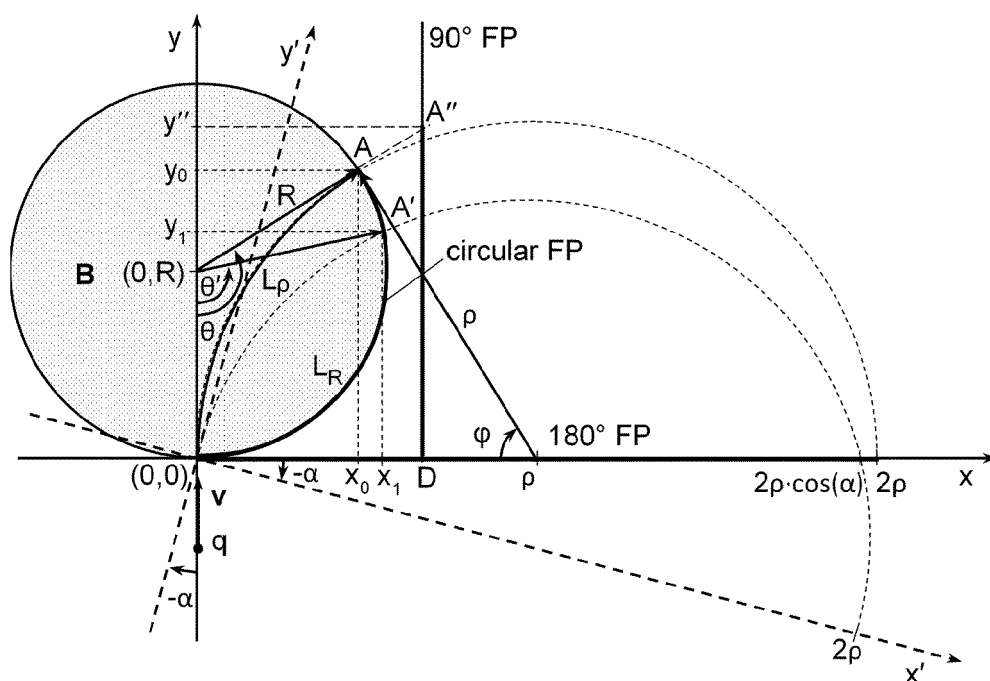


Fig. 5

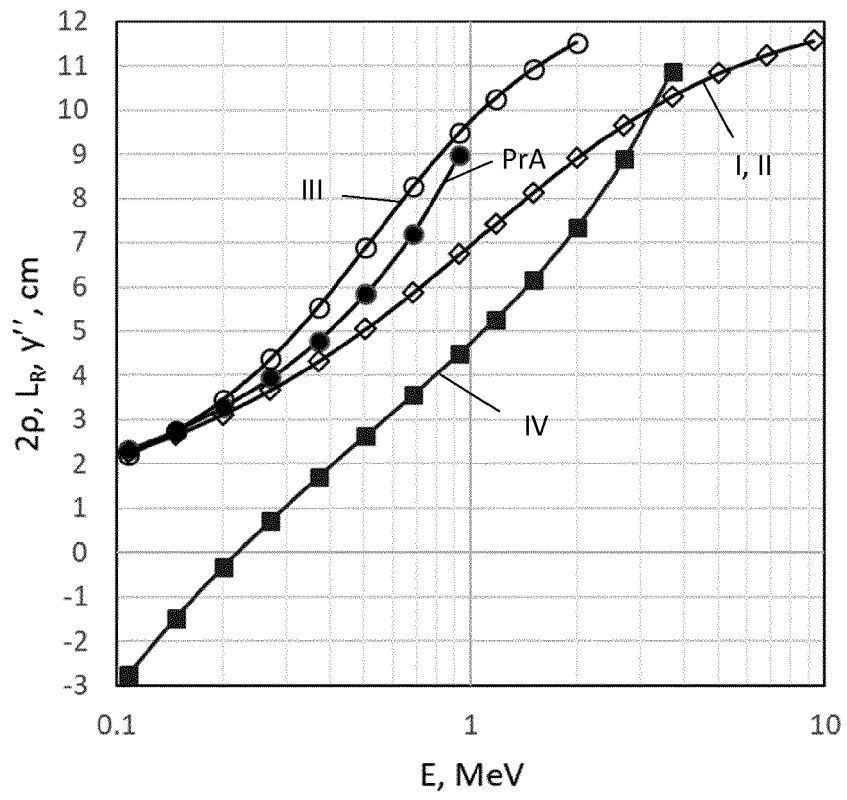


Fig. 6



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Place of search The Hague		Date of completion of the search 28 April 2021	Examiner Peters, Volker
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