ON THE EXISTENCE OF PARTICLES OF MASS $2m_e \leqslant \mu \leqslant 25m_e$

A. N. GORBUNOV, V. M. SPIRIDONOV,* and P. A. CERENKOV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

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Experiments have been carried out with a cloud chamber in a magnetic field with the aim of detecting a possible production of particles of mass $2m_e$ to $25m_e$ in a lead target placed in the bremsstrahlung beam of the 265 Mev synchrotron of the Physics Institute of the Academy of Sciences. It is shown that if particles do exist with masses between $2m_e$ and $25m_e$, spin $\frac{1}{2}$, and a lifetime greater than 10^{-9} sec, then the cross section for their production by electromagnetic interactions is smaller than the expected value by more than two orders of magnitude.

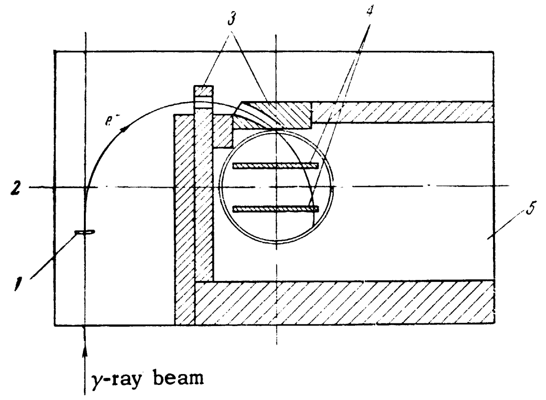
INTRODUCTION

THE question of the existence of light particles of mass equal to several electron masses has been investigated previously in a number of papers. To explain the anomalous scattering of β particles in the neighborhood of radioactive sources, Skobel'tsyn[1-3] proposed the existence of "heavy electrons" of masses $(3$ to $7) m_e$.† In other papers[4-6] on the investigation of penetrating particles in extensive showers in cosmic rays, hypotheses were also introduced on the possible existence of particles of masses $(5$ to $10) m_e$. Although the results of the majority of investigations in the field of cosmic rays left no place for such particles, nevertheless it appeared to us to be useful to set up special experiments, which would enable us to give a definite answer to this question. Since quantum electrodynamics does not place any restrictions on the existence of particles of spin $\frac{1}{2}$ and with masses intermediate between the mass of the electron and the mass of the meson, then, if such particles do exist, they must be produced as the result of a pair-production process with an effective cross section that is inversely proportional to the square of the particle mass. Thus, one might expect that in the case that particles of mass μ do exist, their yield from a target placed in the bremsstrahlung beam of a synchrotron should be, roughly speaking, smaller by a factor of μ^2 than the yield of electron pairs.

As the particle detector we utilized a cloud chamber in a magnetic field, and we identified the particles by their energy losses after passage through lead absorbers.

*Deceased.

†Here and later m_e stands for the electron mass.



Schematic diagram of the experiment: 1) lead target, 2) cloud chamber, 3) system of diaphragms, 4) plates in the cloud chamber, 5) magnet pole.

DESCRIPTION OF THE EXPERIMENTAL ARRANGEMENT

A schematic diagram of the experiment is shown in the figure. Negative particles produced in the lead target 1 of 1 mm thickness by a bremsstrahlung beam from the 265-Mev synchrotron of the Physics Institute of the Academy of Sciences were deflected by a magnetic field through approximately 180° and were introduced through a "window" sealed by an organic film of $70\,\mu$ thickness into the cloud chamber 2 of 30 cm diameter and 8 cm depth, filled to a total pressure of 1.6 atmos by a mixture of helium and argon in the ratio of 50 : 50%. The system of diaphragms 3 placed in the path of the particles, and an appropriate choice of the position of the target 1 enabled us to select for recording those particles which were produced with a momentum of (93 ± 3) Mev/c and emitted at an angle of 3 to 5° to the axis of the bremsstrahlung beam from the synchrotron. In order to identify the particles two

TABLE I. Number of particles that have penetrated the first plate with momenta exceeding $(pc)_I$

$(pc)_I$, Mev	Observed number of particles	Expected total number of electrons and particles of mass μ.									
		m_e	m_e; $2m_e$	m_e; $3m_e$	m_e; $5m_e$	m_e; $8m_e$	m_e; $10m_e$	m_e; $15m_e$	m_e; $20m_e$	m_e; $25m_e$	m_e; $30m_e$
70.6	2	1.5	581	795	449	167	107	38.5	20.5	10.5	6.5
67.4	4	4.9	773	902	469	174	112	41.9	23.9	13.9	9.9
64.2	12	12.5	972	1001	493		119	50	31.5	21.5	17.5
61.0	28	26	1148	1083	517	198	134	63	44.6	34.6	30.6
57.8	44	42	1312	1147	541	215	150	79	60.6	50.6	46.6
54.6	78	72	1497	1246	580	246	181	109	91	81	77
51.4	141	111	1688	1332		286	220	148	130	120	116
48.1	228	164	1865	1420	684	339	274	202	183	173	169
44.9	337	230	2054			405	340	268	249	239	235
41.7	459	314	2243	1631	840	489	424	352	333	323	319
38.5	615	443	2497			617	554	482	462	452	448
35.3	780	590	2742	1957	1118	765	701	628	609	599	595

lead plates (4) each 9.9 mm thick were placed inside the cloud chamber at a distance of 10 cm from each other. The cloud chamber was illuminated by a flash lamp of type IFP-1500 and was photographed by a stereoscopic camera with low-distortion objectives of type Gelios-42 specially designed for taking pictures through a thick glass.

The method of synchronizing the cloud chamber and the synchrotron[7,8] allowed the particles to be introduced into the working volume of the cloud chamber after the expansion in the cloud chamber was completed. This eliminated the distortion of tracks associated with the movement of gas during the expansion period which is particularly noticeable in a cloud chamber which has plates situated within the working volume. The false curvature of the tracks in our chamber did not exceed $0.1\ m^{-1}$. The cloud chamber was placed in a magnetic field $H = (10.7 \pm 0.1) \times 10^3$ Gauss.

EXPERIMENTAL RESULTS

A total of 20,500 tracks of negative particles of momentum 93 Mev/c incident on the first lead plate was recorded in the cloud chamber. The momenta were measured in the case of those negative particles which passed through the plate and which were not accompanied by positrons (which could be produced as a result of a cascade process in the plate). The numbers of particles which passed through the first plate and retained a momentum greater than $(pc)_I$, are given in Table I (column 2).

A small number of particles which had passed through both lead plates were also recorded. The momenta of these particles after they had emerged from the second plate are given in Table II together with their momenta on leaving the first plate.

TABLE II. Momenta of particles that have penetrated both lead plates

Momentum after the first plate $(pc)_I$, Mev	Momentum after the second plate $(pc)_{II}$, Mev	Momentum after the first plate $(pc)_I$, Mev	Momentum after the second plate $(pc)_{II}$, Mev
61	27.3; 17.7; 9,6	51.4	28.9; 27.3; 25.7; 19.3; 12.8
57.8	22.5; 16.0; 14,5		
54.6	14.5; 11.2; 9,6	48.1	19.3; 16; 11.2; 6.4

DISCUSSION OF RESULTS

To estimate the expected number of particles of mass μ incident on the first plate we integrated over the bremsstrahlung spectrum (taken approximately in the form $1/E$) the effective cross section for the production of electron pairs, in which in place of m_e we utilized various values of the mass μ from $2m_e$ to $30m_e$. The expected numbers N_μ of particles of mass μ obtained as a result of such an estimate, on the assumption that there exist both electrons and particles with the given value of the mass, are the following ones (the total number of particles recorded before the first plate is equal to 20.5×10^3):

$\mu =$	1	2	3	5	8	10	15	20	25	30
$N_\mu =$	$20{,}5 \cdot 10^3$	$3.8 \cdot 10^3$	$1.7 \cdot 10^3$	580	180	110	38	19	9	5

We then calculated the probability $W(bl - 1, y_0)$ that the particle on passing through the first lead plate will lose just by radiation alone such an amount of energy that $E/E_0 \geq \exp(-y_0)$ (where

TABLE III. Number of particles that have penetrated both lead plates and which have a momentum in excess of $(pc)_I$ after the first plate, and in excess of 19.3 Mev after the second plate

$(pc)_I$	Expected number of particles of mass μ equal to:										Observed number of particles
	1	2	3	5	8	10	15	20	25	30	
65.7	0.35	580	830	450	170	107	37	19	9	5	0
63	0.57	650	860	460	170	107	37	19	9	5	1
61	0.85	720	905	470	170	107	37	19	9	5	2
57.8	1.13	760	930	470	170	107	37	19	9	5	2
54.6	1.2	790	950	470	170	107	38	19	9	5	5

E_0 is the initial, and E is the final energy of the particle). According to Heitler,[9] this probability is given by the following formula

$$W(bl-1, y_0) = (bl-1, y_0)!/\Gamma(bl),$$

where $(bl-1, y_0)!$ is the incomplete Γ function; $b = a\overline{\varphi}N$ (for lead in the case $\mu = m_e$ $b = 2.6$ cm^{-1}, $a \approx 20.0$); $\overline{\varphi} = z^2r_0^2/137$; N is the number of atoms per cm^3; l is the thickness of the plate in centimeters (in view of the inclination of the plate towards the bottom of the chamber and the angle of incidence of particles on the plate, we obtain in our case $l = 1.13$ cm). The quantity $(bl)_\mu$ for particles of mass μ was chosen in the form

$$(bl)_\mu = (bl)_{m_e}/\mu^2.$$

Table I lists, together with the observed number of particles which have passed through the first plate with momentum greater than $(pc)_I$, also the expected numbers of electrons that have passed through the plate, and also the total expected numbers of electrons and particles of mass μ ($\mu = 2m_e$, $3m_e \ldots$). It is seen from the table that the observed number of particles which have passed through the first plate with small radiation energy losses (6.6 Mev $\leq \Delta E_{rad} \leq$ 22.5 Mev)* agrees with the expected number of electrons. In the case of higher radiation energy losses ($\Delta E_{rad} >$ 22.5 Mev) the observed number of particles that has passed through the first plate becomes greater than the expected number of electrons, with this difference increasing as the radiation losses increase. This difference may be due to the recording of cascade electrons which could occur in the case when the cascade positron did not leave the plate. It is evident that the number of such "false" events will increase as the final particle momentum diminishes.

It can further be seen from Table I that if particles of mass from $2m_e$ to $25m_e$ did exist, then the numbers of recorded particles, particularly in the range of high momenta after the first plate, would have been considerably greater than the observed values.

Even more convincing is the comparison of the observed number of particles which have passed through both plates and which have retained after the second plate a momentum greater than 19.3 Mev with the expected numbers of particles of various masses. The results of such a comparison are given in Table III for different values of the momenta after the first plate. It can be seen from the table that the number of observed particles which have passed through both plates is in satisfactory agreement with the expected number of electrons and contradicts the assumption of the existence of particles with masses in the range from $2m_e$ to $25m_e$.

*$(pc)_I$ = 54.6 Mev.

CONCLUSION

Thus, the results of the experiment show that if there do exist particles of masses between $2m_e$ and $25m_e$ and of spin $\frac{1}{2}$, and having a mean lifetime in excess of several 10^{-9} sec, then the effective cross sections for their production in electromagnetic interactions do not exceed the values shown in Table IV.

TABLE IV

Particle mass in units of m_ec^2	Expected cross section $\overline{\Phi}$ in cm^2	Observed cross section $\overline{\Phi}_{obs}$ in cm^2
2	$9.6\cdot10^{-25}$	$<3\cdot10^{-27}$
3	$4.2\cdot10^{-25}$	$<10^{-27}$
5	$1.5\cdot10^{-25}$	$<6,8\cdot10^{-28}$
8	$6\cdot10^{-26}$	$<7\cdot10^{-28}$
10	$3.8\cdot10^{-26}$	$<7\cdot10^{-28}$
15	$1.7\cdot10^{-26}$	$< 0^{-27}$
20	$9.6\cdot10^{-27}$	$< 0^{-27}$
25	$6.1\cdot10^{-27}$	$<10^{-27}$

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