uncertainty of the individual tracks tends to give a value which is too high. We consider $3 \cdot 7 \pm 0 \cdot 5$ m.e.v. as the most probable value from our measurements.

The most reasonable assumption as to the formation and disintegration of radio-helium are the processes:

$$ {}^{9}_{4}\mathrm{Be} + {}^{1}_{0}n \rightarrow {}^{6}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \quad (1) $$

$$ \text{and } {}^{6}_{2}\mathrm{He} \rightarrow {}^{6}_{3}\mathrm{Li} + e^{-} \quad (2) $$

If the energy release in (2) is $3 \cdot 7$ m.e.v., the mass of ${}^{6}_{2}$He would be $6 \cdot 0207$, using the masses given by Oliphant[2]. Recently Oliphant has reported[3] that (1) takes place even if the bombarding neutrons have only $1 \cdot 5$ m.e.v. kinetic energy. If these figures are applied in (1), it follows that the energy available for the breaking up of the intermediate ${}^{10}_{4}$Be nucleus into He and ${}^{4}_{2}$He is $0 \cdot 8$ m.e.v., which does not seem unreasonable.

We wish to thank Prof. N. Bohr for his interest in the work, and the Radium Institute of Copenhagen for the gift of the emanation.

T. BJERGE.
K. J. BROSTRÖM.
Institute for Theoretical Physics,
Copenhagen.
July 31.

[1] See preceding letter.
[2] M. L. Oliphant, NATURE, 137, 396 (1936).
[3] M. L. Oliphant, Copenhagen Conf. 1936 (unpublished).

Passage of Fast Electrons through Matter

WHEN a fast electron passes through matter, it loses its energy mainly by emission of a few large quanta of radiation (*Bremsstrahlung*). The radiation quanta are absorbed again, the absorption being due mainly to the creation of pairs. Thus, in a *thick sheet of matter*, a fast primary electron produces quite a number of secondary positive and negative electrons, which appear as a *small shower* giving rise to triple coincidences, etc.

Using the cross-sections for the above processes as obtained from relativistic quantum mechanics[1], we have calculated the probability for the production of secondary electrons with an energy greater than E, say, when a primary electron of energy E_0 passes through a sheet of matter of thickness L. The result can be expressed in the same form for all materials if the thickness L is expressed in certain units characteristic for the material. The unit thickness ($L = 1$) corresponds to:

$0 \cdot 40$ cm. Pb; $7 \cdot 4$ cm. Al; 33 cm. H_2O; 280 m. air.

The average number of positive *or* negative electrons emerging from the sheet depends only on L and the ratio E_0/E. It is given in the accompanying table (the total number of positive + negative electrons being twice the corresponding figure given in the table):

E_0/E	20	100	400	1000	10,000
$L = 2$	0·5	1·3	2	2·5	3·7
3	0·7	1·8	3·4	4·4	7
4	0·7	2	3·8	5·2	8·6
5	0·5	1·8	3·8	5·4	9·3
7	0·2	1·2	3	4·7	10·3
10	0	0·5	1·8	3	8·4

The results are only valid for $E \gg mc^2$.

The table shows that the maximum number of secondaries is produced at a thickness L_m of about $3 \cdot 5 - 5$, increasing slowly with E_0/E. $L = 4$ corresponds to $1 \cdot 6$ cm. lead. For this thickness a primary electron of 2×10^9 e.v. produces, for example, on the average 2 positive and 2 negative electrons with energies greater than 20×10^6 e.v.

There can be no doubt that the process discussed above is responsible at least for a large part of the triple-coincidences obtained by Rossi and others. The thickness $L_m = 4$ ($1 \cdot 6$ cm. lead) at which the number of secondaries is a maximum agrees well with the maximum of Rossi's well-known curves[2].

Showers of this sort can also be produced by hard light quanta. After having travelled an average distance $L = 1 \cdot 7$, the light quantum creates a pair, each electron of which produces secondaries in the way described above.

A more detailed discussion of these processes and in particular of the higher stages (tertiary, quaternary . . . electrons) will be given elsewhere. The latter have to be taken into account for large values of L and E_0/E.

H. J. BHABHA.
Cambridge.
W. HEITLER.
Bristol.
July 29.

[1] Bethe and Heitler, *Proc. Roy. Soc.*, A, **146**, 83 (1934).
[2] Int. Conf. Nuclear Physics, London, 1934.

Intrinsic Uncertainty of Reference Frames

PHYSICAL ideas which seem at first sight somewhat arbitrary become, as Eddington has stressed, almost inevitable when the relativity principle is taken to its proper conclusion. As examples may be quoted the law of gravitation, in which the radius of curvature anywhere in the universe is proportional to the corresponding amount of matter there, and the principle of unit weights (equal *a priori* probabilities) in statistical mechanics.

Eddington has pointed out further, following earlier ideas of Mach, that the *ad hoc* introduction in quantum theory of a term m to represent mass is theoretically unsatisfactory, in view of the necessary dependence of such a term on the remaining unspecified matter. It seems logical to realize not only that relativity has denied the absolute independence of mass, space and time; but also that these concepts should rigorously be regarded merely as aspects of the configuration and changes of configuration of matter. On any kind of atomic theory it follows that these three associated concepts of mass, space and time are all statistical in character.

Any mechanical properties of a system will be implicitly affected by fluctuations in our frame of reference. If in particular we use the rest of the world as our reference frame, there will be an uncertainty of order $R/\sqrt{N}$, where R is the radius of the universe, and N the number of particles it contains. From this uncertainty, Eddington has considered what term should represent the 'reference mass' of the universe. If this statistical view of the origin of mass is accepted, it does not seem unreasonable that we should assume a corresponding uncertainty of the conjugate co-ordinate, proper time, of order h/mc^2 or $R/c\sqrt{N}$.

The above argument could thus be regarded as one approach to Flint's assumption that in addition to the usual limitations imposed by Heisenberg's uncertainty principle, there is a limit to the subdivision of proper time, from which postulate he