Eindringen in die Elektronenhülle gestattet, ist dieser Befund wohl verständlich. Immerhin ist es überraschend, daß die Abweichung des Kohlendioxyds von der Kugelform und ein etwaiger Formfaktor nur von untergeordneter Bedeutung zu sein scheinen.

5. Zusammenfassend ist also festzustellen, daß die Näherung von Kihara einen bedeutenden Fortschritt in der theoretischen Behandlung der Thermodiffusion darstellen dürfte. Im vorliegenden Fall wurde das Eindringen in die numerische Behandlung des Problems sehr glücklich erleichtert, indem zunächst die Funktion S_1/Q_1 sich auf einen Ausdruck reduzieren ließ, der nur noch die genau bekannten Molekelmassen enthielt. Dadurch konnte die Temperaturfunktion C unabhängig von der Kenntnis der Omegaintegrale und Wirkungsquerschnitte gleich zu Anfang festgelegt und die Anwendbarkeit der Kihara-Näherung geprüft werden. Anschließend stellte sich heraus, daß S_2 praktisch temperaturunabhängig ist, worauf die Bestimmung der übrigen Größen sich fast von selbst ergab.

Eine so einfache Analyse ist jedoch nicht bei allen Gaspaaren durchführbar. Eine Prüfung anderer Stoffpaare bleibt indessen dringend erwünscht, wobei man aber von vornherein die Messung *wahrer* und nicht nur *mittlerer* Thermodiffusions-Faktoren ins Auge zu fassen hat. Ebenso wie die Messung wahrer spezifischer Wärmen die Behandlung kalorischer Probleme seinerzeit gefördert hat, wird erst die Kenntnis der *wahren* Thermodiffusions-Faktoren die ausstehenden Probleme der Gaskinetik lösen helfen.

The Determination of Meson Multiplicity at about 20 BeV

C. B. A. McCusker

Dublin Institute for Advanced Studies

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Die bei der Bestimmung der Multiplizität von solchen Mesonen, die bei Zusammenstößen von Nucleonen mit Energien von ungefähr 20 BeV entstehen, auftretenden Schwierigkeiten werden diskutiert. Es ergibt sich, daß es notwendig ist, bei dieser Untersuchung,

a) Wasserstoff zu verwenden, um Verwechslung mit Kaskaden innerhalb des Kernes zu vermeiden,

b) dünne Schichten zu benutzen, um die Zahl der Kaskaden nach dem ursprünglichen Stoß möglichst klein zu halten,

c) die Empfindlichkeit des Geräts gegen Ereignisse mit wenigen oder nicht geladenen Teilchen soweit als möglich zu reduzieren.

Nimmt man an, daß viele der geladenen Teilchen, welche bei Zusammenstößen mit Kohlenstoff und schwereren Elementen erzeugt werden, die Folge von Kaskaden innerhalb des Kernes sind, so scheint es derzeit möglich, unter Beachtung der obigen Punkte das ganze experimentelle Material in Einklang zu bringen. Die Multiplizität von Mesonen, welche in Zusammenstößen von Nucleonen mit Nucleonen erzeugt werden, scheint etwas kleiner zu sein, als sie in den Theorien von Fermi und Heisenberg vorausgesagt wurde.

Recently many experiments have been carried out to determine the multiplicity of meson production in nucleon-nucleon encounters at about 20 BeV. Many of the experimenters [1–6] have agreed that at this energy the multiple production of mesons does not predominate and that in carbon and heavier elements many of the shower particles are due to cascading within the nucleus. Others however have come to a different conclusion [7–10]. Because of this disagreement it seems worth while

[1] E. O. Salant, J. Hornbostel, C. B. Fisk, and J. E. Smith, Phys. Rev. **79**, 184 [1950].
[2] C. B. A. McCusker and D. D. Millar, Proc. Phys. Soc., Lond. A **65**, 758 [1952].
[3] W. D. Walker, N. M. Duller, and J. D. Sorrels, Phys. Rev. **86**, 865 [1952].
[4] A. B. Weaver, Phys. Rev. **90**, 86 [1953].
[5] C. B. A. McCusker, N. A. Porter, and B. G. Wilson, Phys. Rev. **91**, 384 [1953].
[6] N. M. Duller and W. D. Walker, Phys. Rev. **93**, 215 [1954].
[7] O. Haxel and H. Schultz, Z. Naturforschg. **9a**, 178 [1954].
[8] H. Schultz, Z. Naturforschg. **9a**, 419 [1954].
[9] G. Bertolino, C. Cini, P. Colombino and G. Wataghin, Nuovo Cim. **9**, 407 [1952].
[10] P. Colombino, S. Ferroni and G. Wataghin, Nuovo Cim. **11**, 572 [1954].

to examine the difficulties of the investigation carefully, to try to determine the necessary qualities of a suitable apparatus, and to reconcile, if possible, the various results.

The Experimental Difficulties

It is obvious that it is preferable to use hydrogen as the target material. If any other element is used cascading within the nucleus may occur. It then becomes very difficult to disentangle the results of the initial collision and the subsequent cascade. The photographic plate contains little hydrogen. Moreover it is no longer possible to believe that the absence of heavy prongs in a star guarantees a nucleon-nucleon collision[11–13]. Hence the plate is not a very suitable instrument for this purpose and most of the investigators have used counters or cloud chambers. Even so it is not easy to get hydrogen in a suitable form. Liquid hydrogen[4] requires special facilities, has a low density and a high rate of evaporation. Hydrogen at high pressure[14] requires very bulky containers or a high pressure cloud chamber. The excellent technique of Shutt and his coworkers cannot yet be used in the 20 BeV region because of the lack of a suitable accelerator. Thus the more detailed investigations have been made with hydrogen combined with some other element usually carbon. This requires a second run of the apparatus with an amount of carbon equal to the carbon combined with the hydrogen. It is this so called subtraction technique which it is proposed to examine in detail.

The Subtraction Technique

The high energy nucleon component forms only a small fraction of the incident cosmic radiation. This leads to two difficulties. In the first place one cannot use very thin layers of paraffin, because to do so would mean that very few events would be observed. Secondly one must exclude events containing only one charged penetrating particle because otherwise the great majority of events would be due to μ-mesons. Consider the first of these difficulties. A thick layer unfortunately makes secondary interactions likely. Suppose a beam of N_0 nucleons is incident on a layer of paraffin of thickness L. At a depth x there will remain $N_0\, e^{-x/\lambda}$ which have not yet collided. λ is the interaction mean free path which is assumed to be the same for all shower particles. In the next $\mathrm{d}x$, $C\, N_0\, e^{-x/\lambda}\mathrm{d}x/\lambda$ collide with hydrogen, C being the fraction in any mean free path colliding with hydrogen. Suppose that, on average a nucleon-nucleon collision results in p charged secondaries. The probability that at least one of the charged secondaries from a nucleon-nucleon collision at depth x collides before leaving the paraffin is $1-\exp[-p(L-x)/\lambda]$. Therefore the number of particles colliding with hydrogen between x and $x+\mathrm{d}x$, at least one of whose charged secondaries suffers one or more collisions before leaving the paraffin, is

$$C\, N_0\, e^{-x/\lambda}\left\{1-e^{-p(L-x)/\lambda}\right\}\mathrm{d}x/\lambda\,.$$

Hence the total number of nucleons colliding with hydrogen at least one of whose charged secondaries suffers one or more collisions before leaving the paraffin is

$$N = C\, N_0\left[(e^{-L/\lambda}-1)-\left\{\frac{e^{-pL/\lambda}}{p-1}\left(1-e^{-(p-1)L/\lambda}\right)\right\}\right].$$

This is to be compared with the total number colliding with hydrogen which is given by

$$N_{\text{coll}} = C\, N_0\, e^{-L/\lambda}.$$

The ratio N/N_{coll} can at once be computed for any given p and L. This has been done for $p=1.75$ and 4 and for $L=\lambda/4$, $\lambda/2$, λ, and $2\,\lambda$. The results are given in Table 1.

p \ L	$\lambda/4$	$\lambda/2$	λ	$2\,\lambda$
1.75	.22	.38	.60	.82
4	.37	.6	.8	.95

Tab. 1. Fraction of nucleon-nucleon collisions resulting in at least one other collision for various thicknesses of producing layer for plural and mildly multiple theories of meson production.

It should be noted that the neutral particles, which themselves will cascade, often producing charged secondaries, have been ignored, and that only one secondary collision (often there will be more) has been stipulated, and finally that $p=4$

[11] C. B. A. McCusker and F. C. Roesler, Phys. Rev. **91**, 769 [1953].
[12] J. Y. Mei and E. Pickup, Canad. Phys. **30**, 430.
[13] G. Cocconi, Phys. Rev. **93**, 1107 [1954].
[14] Kusmoto, S. Miyaka, K. Suga, and Y. Watase, Phys. Rev. **90**, 998 [1953].

represents only a small multiplicity. Experimental evidence corroborating the calculation is given in Fig. 1. This shows the average number of ionizing particles per shower for different thicknesses of water as a producing layer. The apparatus required at least two penetrating particles to trigger[15] it. Both from the experimental results and the calculation it is obvious that producing layers of $< \lambda/4$ must be used. Otherwise the subsequent cascading will completely falsify the picture.

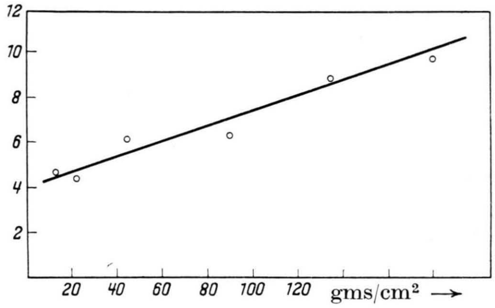

Fig. 1. Graph of the number of charged particles per shower against depth of water.

Now as to the difficulties due to selection. At least two penetrating particles must occur and thus events in which zero or one charged penetrating particle is produced are rejected. This is a serious limitation for on any theory such events will sometimes occur (e. g. $P + N \rightarrow N + N + \pi^+ + \pi^0$). Further if any apparatus is set to detect $\geqslant 2$ charged penetrating particles its efficiency for a 2 fold event will not be 100% — in general it will be appreciably less and even 3 fold events will not always be registered. For example, in the apparatus of McCusker et al. the counters immediately under the paraffin were disposed in two trays of twelve counters each, in contact with each other, their axes being at 90°. At least two counters in the lower tray had to be discharged for the apparatus to trigger. Table 2 gives the number of cases in which when two and only two of the lower counters triggered, different numbers of counters in the top tray were discharged.

It can be seen that when it is known that at least two particles had traversed the lower tray there

No. of top counters discharged	0	1	2	3	4	5	6	7	8	9	10	11	12
No. of events.	340	1090	982	279	82	26	9	3	1	2	0	0	1

Tab. 2.

were 1430 cases when < 2 counters were discharged in the upper tray. Hence the efficiency of this apparatus for a 2 fold event was not greater chan 50% and yet the selection in this case was as simple as is practicable with a counter set up.

Design of the Experiment

It follows from this discussion that it is difficult, if not impossible, to determine with either a counter set or a counter controlled cloud chamber the true average multiplicity of charged penetrating particles from a nucleon-nucleon collision at about 20 BeV. The best that can be done is to set up an upper limit. Moreover if this upper limit is to be useful the bias of the apparatus must be as small as possible. That is to say, the apparatus must be capable of responding to events containing only 2 charged penetrating particles.

Secondly if the paraffin layer is thicker than $\lambda/4$ what is measured will not be the true multiplicity in the original nucleon-nucleon collision but the end product of a complex cascade. The determination of λ thus becomes of great importance.

The interaction Mean Free Path

Evidence concerning λ, the interaction mean free path for nucleon-nucleon collisions is conflicting. Photographic plate work[16] seems to establish a geometric cross section for the interaction of all shower particles with elements as light as carbon. Walker and his coworkers give an interaction mean free path of 31^{+35}_{-7} g/cm² for hydrogen. Weaver found the cross sections for carbon, aluminium and lead to be proportional to the geometric cross sections. For energies as low as 2 BeV workers with the Brookhaven cosmotron[17] have found a cross section for nucleon-nucleon interactions of $\sim$ 43 mb. (i. e. $\sim$ 2/3 geometric).

[15] See C. B. A. McCusker, H. Messel, D. D. Millar, and N. A. Porter, Phys. Rev. **89**, 1172 [1953].

[16] C. F. Powell, Rep. Progr. Phys. **13**, 350.

[17] Hill, Coor, Hornyak, Smith & Snow, Bull. Amer. Phys. Soc. **28**, 54 [1954].

On the other hand Schultz, Regener and his coworkers[18] and Rollosson[19] have claimed that their experiments are best interpreted by assuming a cross section much smaller than geometric. Since it is rather difficult to see how either the photographic plate workers or the cosmotron group can have erred in this matter it seems worth while examining these other results carefully.

In the experiments of Schultz layers of paraffin up to 60 g/cm^2 thick were used. At these thicknesses, as has been shown experimentally, cascading is considerable. The apparatus was incapable of detecting events in which only two charged penetrating particles were produced. It is interesting to consider what the effect on such an apparatus would be of a plural process occurring with geometric cross section.

At thicknesses less than $\lambda/4$ where cascading is unimportant most of the events from hydrogen would be missed. This would be particularly so if, as the Brookhaven group and the results of McCusker et al. suggest, the process $N+P \to P+P+\pi^-$ is rare by comparison with the other processes of single meson production. At thicknesses of $\gg\lambda$ cascading will occur in most cases and hence the events originating from hydrogen will be registered. Thus at the smaller thicknesses the material will behave as though only the carbon were producing detectable showers and at the greater thicknesses it will behave as though the hydrogen were as effective as carbon. This is in fact what Schultz found (see Schultz, Fig. 6). Other interpretations of the results are, of course, possible but the apparatus is not capable of distinguishing between them.

The results of Rollosson and Regener and his coworkers are discussed in the appendix since the arguments involved are rather technical. It is concluded that the small cross section for nucleon-nucleon interactions at ~20 BeV is not established.

Conclusion

From the above discussion it seems necessary in this investigation

a) to use hydrogen, to avoid confusion due to cascading within the nucleus,

b) to use thin layers of material to avoid cascading subsequent to the original collision,

c) to reduce the bias of the apparatus against events with few or no charged particles as far as possible*.

Bearing these points in mind, it seems possible at the moment to reconcile all the experimental evidence providing it is assumed that at about 20 BeV multiple production of mesons does not predominate and that for carbon and heavier elements many of the charged particles produced are due to cascading within the nucleus. The average multiplicity of mesons produced in nucleon-nucleon collisions at this energy appears to be less than predicted by either the theories of Fermi or of Heisenberg. At higher energies of course, the picture may be very different[20].

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Appendix

For the following reasons it seems likely that the experiments of Froman, Kenney and Regener may overestimate the interaction mean free path of the neutral primaries.

If $\Sigma_1 = 0$[21] the events (apart from background) will consist of all cases in which a neutron strikes Σ_2 and produces a suitable shower. These events can be divided into two classes.

α) Those in which the neutron crosses the Σ_1 tank and

β) those in which it does not. If $\Sigma_1 \neq 0$ the events recorded as A B C_2 D—E will consist of

a) α type events in which the neutron does not interact in Σ_1,

b) β type events. This rate will be unchanged.

[18] D. Froman, J. Kenney and V. H. Regener, Phys. Rev. **91**, 707 [1953].

[19] G. W. Rollosson, Phys. Rev. **87**, 71 [1952].

* It is interesting in this connection to note that even the high pressure hydrogen filled diffusion cloud chamber is not always free from such a bias. For instance in the case of N-P-collisions it has not so far been possible to identify reactions giving only 1 charged particle. In P-P-collisions this difficulty does not occur and in 160 events only 2 cases of multiple production have been found.

[20] C. B. A. McCusker and F. C. Roesler, Phys. Rev. **91**, 769 [1953].

[21] The authors' terminology is used.

c) α type events that interact in Σ_1 but do not send an ionizing particle through E. When an interaction occurs near the top of the tank the probability of this happening may be considerable.

d) Events produced by neutrons crossing Σ_1 not in the direction of Σ_2 or protons crossing in any direction, which interact in Σ_1 so as to send a neutron (which suitably interacts) into Σ_2 without sending an ionizing particle into E. This effect obviously increases with the thickness of Σ_1.

e) α type events that interact as $N + N \rightarrow N + N + \pi^\circ$, the γ-rays from which do not materialize until after crossing E. Since this type of event is very important in the difference produced by deuterium the consequences of a lack of detection need careful study.

Suppose x neutrons cross Σ_1 and Σ_2 per hour and that with $\Sigma_1 = 0$ a fraction α interact in Σ_2. Suppose that at these energies plural production predominates so that the possible interactions are

$$N + N \rightarrow N + P + \pi^- \qquad (1)$$

and

$$N + N \rightarrow N + N + \pi^\circ. \qquad (2)$$

Suppose (1) is detected with 100% efficiency and (2) is not detected and that a fraction β of the x particles interact in Σ_1. These are very simplifying assumptions but they are probably not too far out for most primary energies and Σ_1 not too thick. Then the number of such events per hour producing A B C_2 D — E is

$$\alpha \left[x (1 - \beta) + \frac{\beta a}{2} \left\{ \alpha (2 - \alpha) \right\} \right]$$

i. e.

$$\alpha x \left\{ 1 - \frac{\alpha}{2} \cdot \beta \right\}$$

instead of the result $\alpha x (1 - \beta)$ which is obtained assuming 100% detection efficiency for all interactions. The effect is obviously considerable and such as to reduce the observed cross section.

It is obvious that many of these criticisms also apply to Rollossons experiment.

Eine direkte Bestimmung von Thermodiffusionskoeffizienten in Flüssigkeiten*

Von Horst Korsching

Aus dem Max-Planck-Institut für Physik, Göttingen

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Es wird eine neue Anordnung beschrieben, die es gestattet, Thermodiffusionskoeffizienten nach der Methode der optischen Ablenkung zu bestimmen. An einigen organischen Substanzen werden Messungen durchgeführt.

Die Konzentrationsänderungen von Flüssigkeitsgemischen in einem Temperaturgradienten sind durch Ludwig und Soret seit langem bekannt. Die Übertragung des Clusius-Dickelschen Prinzips auf Flüssigkeiten gestattet eine bequeme Messung[1] der Trenneffekte, und mit Hilfe der Theorie läßt sich hieraus der Elementareffekt berechnen. Jedoch gehen dabei viele Näherungen ein, deren Auswirkungen schwer quantitativ abzuschätzen sind. Deshalb erscheint eine direkte Messung des Elementareffektes wünschenswert.

Zur Messung des Thermodiffusionskoeffizienten wurde die Methode der optischen Ablenkung benutzt. Eine starke Lichtquelle wird durch ein Filter auf eine Lochblende von einigen hundertstel Millimeter Durchmesser abgebildet. Im Abstand ihrer Brennweite ist die Kollimatorlinse angeordnet, so daß aus ihr paralleles Licht austritt. Das Lichtbündel durchquert die mit zwei Fenstern versehene Meßzelle und wird darin bei Vorhandensein eines Temperaturgradienten abgelenkt. Die Größe der Ablenkung wird durch ein dahinter befindliches Fernrohr mit Okularmikrometer gemessen.

Tanner[2] und später Thomaes[3] haben bereits auf diese Weise eine Reihe von Soret-Koeffizienten bestimmt. Die Meßzellen beider Apparaturen sind aber verhältnismäßig groß, ungefähr 50 ccm. Dadurch ergibt sich die Möglichkeit von störenden Konvektionsströmungen bei nicht ganz gleichmäßiger Temperatur der heißen oder der kalten Seite. Es wurde deshalb eine Meßzelle entwickelt, die ein sehr kleines Volumen, etwa 0,25 ccm, hat und die durch ihre Schmalheit strömungserschwerend war. Zusätzlich wirkt sich das kleine Volumen substanzsparend aus.

* Zum Teil vorgetragen auf der Physikertagung in Goslar am 23. 4. 1954.

1 H. Korsching, Naturwiss. **31**, 348 [1943].

2 C. C. Tanner, Trans. Faraday Soc. **23**, 75 [1927].

3 G. Thomaes, Physica **17**, 885 [1951].