12. IMPACT ON THE DEVELOPMENT OF SUBNUCLEAR PARTICLE PHYSICS OF THE STUDY OF e^+e^- HIGH-ENERGY COLLISIONS

If one looks back over the history of subnuclear particle physics during the last twenty years it clearly emerges that the study of the e^+e^- high-energy collision constituted and still constitutes the main means of obtaining more detailed knowledge in this field. Furthermore, as is obvious from the three preceding sections, the contribution made by Bruno Touschek at the outset and during the development of this approach is absolutely exceptional.

Not only was Touschek the first, at the beginning of 1960, to sense the fundamental importance of this line of research, but he himself contributed to a whole series of subsequent developments such as: the designing of the prototype AdA, in which he was involved directly, the design and performance of the first experiments with this machine which led him to measure the lifetime of the particle bunches and finally to work out the complete theory of the phenomenon, which is correctly referred to in the literature as the Touschek effect. Subsequently Bruno studied one of the instabilities of the beams, caused by the fact that these interact through the (conducting) wall of the vacuum chamber. He provided a substantial clarification of the problem of radiative corrections, which constituted an essential ingredient for the derivation from the experimental counting rates not only of the absolute values but also of the relative values of the collision cross-sections of the various processes. Finally, he made a considerable contribution by discussions, calculations, and advice, to the design of ADONE, which is the first machine of this type, whose design and construction reflect the most advanced optimization criteria at the end of the sixties.

Touschek's direct influence on those who were close to him was outstanding.

Already in a seminar held in 1960 at the Istituto Guglielmo Marconi a few weeks after the one at Frascati, Touschek spoke on the same subjects but in a broader and more complete manner. He also listed at least 16 two-body reactions and the need to take radiative corrections into account.

One of the important consequences of this stimulating action was that N. Cabibbo and R. Gatto[127)] as well as L.M. Brown and F. Calogero[127)] worked out expressions for the collision cross-sections of all the processes foreseeable in the sixties, as final channels of e^+e^- high-energy collision. These results were obtained within the framework of quantum electrodynamics, completed with the introduction of phenomenological form factors to take into account the effect of strong interactions. Together with certain classical results [as far as electrodynamics is concerned[103)]], these constituted the fundamental term of comparison for the analysis of the data from all the experiments made at ACO, ADONE and, to a large extent, the machines which immediately followed.

These experiments, in particular those performed with ADONE[128)], can be divided into two categories, depending on whether they concern purely electrodynamic processes or processes involving strong interactions such as all of those in which a production of hadrons is observed.

The experimental study of the electrodynamic processes performed at ADONE allowed further improvements of the limits of the validity of quantum electrodynamics[129)], and to demonstrate for the first time the photon-photon interaction processes[130)].

The experimental study of the processes with the emission of hadrons showed that an abundant multi-hadronic production begins to occur just at the energies of ADONE[131)]. More precisely, by determining experimentally the ratio

$$R = \frac{\sigma_h}{\sigma_{\mu^+\mu^-}} = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} \tag{14}$$

between the collision cross-section for production in e^+e^- collisions, of at least two hadrons and $\mu^+\mu^-$ pairs, one began to find, already at the energies of ADONE ($W \leq 3$ GeV), a greater value than that calculated by Brown and Calogero[127)], on the basis of purely electrodynamic considerations.

This phenomenon constituted, among others, one of the first proofs of the "parton" structure of hadrons[132)] and the need to identify these partons with quarks [i.e. particles having charge 1/3 and 2/3, of three different types (colours)].

There can be no doubt about the fact that it was Touschek who opened up this major approach, which, right from the beginning in 1960, was in competition, with regard to the study of electrodynamic processes and the possible production of new particles, with the observation of the wide-angle emission of e^+e^- pairs in high-energy proton-proton collisions[133)].

Both of these approaches led, approximately at the same date[134)], to the discovery of the J/ψ, but the wealth of information which could be gathered from a study of all the final channels of the processes initiated in the e^+e^- channel is incomparably greater. In particular, the determination of the ratio (14) is obviously possible only when starting from an e^+e^- collision, which, when studied experimentally at increasingly high energies and with higher resolutions, led to confirmation that multi-hadronic production, which could be recognized but was certainly not conspicuous at ADONE's energy, becomes rapidly a dominating aspect of the phenomenological framework. It was by following this course that the discovery was subsequently made of the ψ' and later of the D and F mesons[135)], whose existence called for the intervention of a new quantum number, charm, as theoretically predicted by S. Glashow, J. Iliopoulos and L. Maiani[136)]. All of these discoveries made the greatest contribution to the substantial change in the theoretical framework of the subatomic particles as from 1970.

Although the process

$$e^- + e^+ \leftrightarrow p + \bar{p}$$

was indicated for the first time by Drell and Zachariasen[102)] for its particular interest as a means of entering the "time-like" region, its experimental study was tackled[137)] only following a theoretical treatment[138)] developed as a natural extension of that relating to one of the many processes which we can today refer to as the "Touschek reactions".

Table 2, taken from the article by Robert R. Wilson on the next particle accelerators[139)], shows in chronological order, and at the same time in increasing energy, the complete family of "storage rings". The list begins with AdA and the first machines mentioned at the end of Section 9 and ends with the accelerators of this type, which are still being constructed or are in the course of design. The list includes a single ring for the only mode e^-e^-, two rings of the pp type, and five of the $p\bar{p}$ type. All of the others are of the e^-e^+ ($\equiv e\bar{e}$) type, i.e. machines following the line of research recognized and initiated by Bruno Touschek. It should be added that also the machines of the type $p\bar{p}$ represent a natural extension and variant to the type $e\bar{e}$.

For his physical insight and design work relating e^+e^- rings and his contributions to the development of this type of machine, the Accademia Nazionale dei XL awarded Bruno Touschek the 1975 Matteucci Medal[141)].

Table 2[a)]

Storage rings

	Year of entry into service	Type	Particles accelerated	Energy per beam (GeV)	Centre-of-mass energy (GeV)	Luminosity [b)] ($cm^{-2} s^{-1}$)
AdA, Lab. Naz. Frascati, Italy (dismantled)	1961	Single ring	e^+e^-	0.25	0.50	*10^{24}*
Princeton-Stanford, USA (rings dismantled)	1962	Tangential rings	e^+e^-	0.56	1.1	*10^{28}*
VEPP 2, Novosibirsk, USSR	1964	Tangential rings	e^+e^-	0.7	1.4	*10^{28}*
ACO, Orsay, Paris, France	1965	Single ring	e^+e^-	0.5	1.0	*5×10^{28}*
ADONE, Lab. Naz. Frascati, Italy	1969	Single ring	e^+e^-	1.5	3.0	*3×10^{29}*
ISR, CERN, Geneva, Switzerland	1971	Single ring	pp	31.0	62.0	*4×10^{31}*
CEA-Bypass, Cambridge, Mass., USA	1971	Single ring	e^+e^-	2.5	5.0	*2×10^{28}*
SPEAR, Stanford, USA	1972	Single ring	e^+e^-	4.2	8.4	$5 \times 10^{31} - 10^{32}$
DORIS, Hamburg, Germany	1974	Single ring	e^+e^-	4.5	9.0	$5 \times 10^{29} - 10^{32}$
VEPP-2M, Novosibirsk, USSR	1975	Single ring	e^+e^-	1.3	2.6	
DCI, Orsay, Paris, France	1975	Intersecting rings	e^+e^-	3.7	7.4	10^{32}
VEPP-3, Novosibirsk, USSR	1977	Single ring	e^+e^-	3.0	6.0	10^{30}
VEPP-4, Novosibirsk, USSR	1978	Single ring	e^+e^-	7.0	14.0	10^{31}
PETRA, Hamburg, Germany	1978	Single ring	e^+e^-	19.0	38.0	10^{32}
CESR, Cornell Univ., USA	1979	Single ring	e^+e^-	8.0	16.0	10^{32}
ISR $p\bar{p}$, CERN, Geneva, Switzerland	1981	Intersecting rings	$p\bar{p}$	31.0	62.0	10^{29}
PEP, Stanford, USA	1980	Single ring	e^+e^-	18.0	36.0	10^{32}
SPS $p\bar{p}$, CERN, Geneva, Switzerland	1981	Single ring	$p\bar{p}$	270.0	540.0	10^{30}
Fermilab $p\bar{p}$, Batavia, USA	1982	Single ring	$p\bar{p}$	1000	2000	10^{30}
VEPP, Novosibirsk, USSR	?	Single ring	$p\bar{p}$	23.0	46.0	?
ISABELLE, Brookhaven, USA	1986	Intersecting rings	pp	400	800	10^{33}
LEP, CERN, Geneva, Switzerland	Late 1980's	Single ring	e^+e^-	86	172	10^{32}
UNK, Serpukhov, USSR	Late 1980's	Intersecting rings	$p\bar{p}$	3000	6000	?

a) The whole of this table has been taken from an article by R.R. Wilson dated January 1980[139], except for certain data *(in italics)* taken from an article by C. Bernardini in 1976[140]. The values given by this latter author always relate to the initial luminosity, whereas Wilson's values relate to subsequent stages in the development of single machines or are simply the "design values" which seem reasonable to attain.

b) The luminosity is the factor to apply to the collision cross-section of a process so as to obtain the number of events which take place per second.

13. OTHER RESEARCH ACTIVITIES DURING HIS FINAL PERIOD IN ROME

Despite Bruno's marked commitment in the development of the e^+e^- rings, he managed to produce, from 1963 onwards, various interesting theoretical papers on a wide range of subjects. The first, in chronological order, was that which he wrote with I.M. Barbour and A. Bietti entitled "A remark on the neutrino theory of light" [51], in which he takes up the old idea put forward by L. de Broglie[142)] [46] and P. Jordan[143)], i.e. to describe photons as an appropriate state of a system composed of two neutrinos. This description was criticized by M.H.C. Pryce[144)], who had shown that it was impossible to construct a circularly polarized photon in this manner. When, much later, S.A. Bludman[145)] suggested that the existence of two different neutrinos could reinstil life into this idea, Touschek, Barbour and Bietti developed a generalization of the original Jordan proposal by introducing a "weighting" factor to distribute the momentum of the photon between the two component neutrinos.

They found, however, that in this more general scheme the resulting photon was *longitudinal,* i.e. not physical, in accordance with what Pryce had found in a much more particular case. This result could, *inter alia,* also be deduced by using the invariance (2) discovered by Touschek.

Later, B. Ferretti and G. Venturi[146)] observed that this negative result was due to the use of only neutrino S states, but that if one also took into account neutrino waves with ℓ different from zero, it was possible to construct photons with the correct states of polarization.

They showed that the difficulties encountered by previous authors were not related to symmetries [i.e. not with Pryce's theorem[144)]] but with causality: starting from a positronium state with any ℓ, it is possible to obtain, with a suitable procedure for passing to the limit for $e = 0$ and $m_e = 0$, a set of ℓ photons (having a zero mass and any ℓ) with spins which are all parallel. Later, these ideas were discussed privately by Ferretti also with Heisenberg, who agreed with the idea that the difficulties were not due to Pryce's theorem, but rather to the use of corpuscular models instead of the corresponding fields.

Another subject to which Bruno devoted his attention during those years, in connection with his university course, was that of statistical mechanics, on which he wrote a fine book with G.C. Rossi (see Section 7) and to which he made two contributions: one [59] is a critical examination of the temperature definition in the relativistic case, the other [60] a discussion of the connection between microscopic reversibility and macroscopic irreversibility.

As Rossi relates about the writing of this book on statistical mechanics [67], Touschek prepared a rather schematic text for each chapter, in English, which he handed to Rossi who rewrote it in Italian so that, as Bruno had requested, "the students could understand it". Touschek was not, however, easily satisfied and the text was, in practice, rewritten three or four times. The work of reading and discussing the subsequent drafts was carried out jointly with a bottle of fine red wine next to Bruno, who repeatedly helped himself and, in a friendly manner, invited his collaborator to do the same.

The book sets out the main part of the work done on "Covariant statistical mechanics" [59] and on "Statistical reversibility" [60]. The first concerns the problem which for a number of years had been dealt with in the literature concerning the law of transformation of the absolute temperature T under Lorentz transformations. In reality, T is completely defined only if it is measured within the centre-of-mass reference frame. But if the thermometer is in motion with respect to this, the answer is ambiguous, since it depends on the physical law adopted for its definition. If the law adopted is that of energy equipartition, i.e. it is stated that $kT/2$ is the kinematic energy per degree of freedom of a thermodynamic system in equilibrium, or the starting point is the relativistic invariant

$$dS = \frac{\delta Q}{T} \quad ,$$

T is clearly an energy, apart from a constant, and thus is transformed as the *time*variable. If, however, the basis taken is the law of the ideal gas

$$pV = RT,$$

and p is defined as the trace (invariant) of the stress tensor, then T is transformed as a *length* parallel to the motion.

Touschek in Catania (1964)

In paper [60], which is much less important and original, Touschek discusses another problem of thermodynamics, namely the link between the reversible microscopic world and the irreversible macroscopic world. His observation is that the macroscopic world appears to us irreversible because we always start from conditions which are extremely ordered and consequently it is necessary to wait a very long time before any fluctuation occurs which is large enough to allow the observer to speak of a macroscopic process in which the entropy diminishes. As a check of this viewpoint, he observes that, if it is correct, the law of rise in time of a fluctuation must be the same, except for time reversal, as that by which a fluctuation is normally observed to disappear. This equality was in fact found to be true by Rossi and Touschek by simulating on a computer the development and decay of the fluctuations of the time average, in an interval of time T, of a dynamic macroscopic variable (Chapter 8, paragraph 49, Figure 49.1 of his book [67]).

The fact that there is an exponential law with the same time constant during the development and decay of a fluctuation is a strong argument in favour of the idea maintained by Touschek, and by others before him, that the macroscopic asymmetry between the phenomena of decay and development of fluctuations which lead to macroscopic irreversibility are, in fact, only the consequence of the method in which the observations are made.

For Gian Carlo Rossi, working with Bruno was a "grandiose" experience. One was always struck by his exceptional physical sense and the originality of his line of thought, which was based on a purely personal point of view. Another striking feature was the speed at which Bruno would always see the grotesque side of situations, which he would point out with short but effective sentences; these were sometimes scathing, and always deeply ironical[147)].

In his paper entitled "What is high energy" [62], Touschek discusses the "possible" milestones which mark the scale of high-energy phenomena. He describes these "milestones" as spots where two or three different "branches", developed independently in low-energy physics (strong, electromagnetic, and weak interactions), might meet. The first point of reference is placed, according to Touschek, at $m_G c^2$ where, despite their weakness, the perturbation theory of the weak interactions must break down. This should happen at $mc^2 = G^{-1/2} \simeq 300$ GeV, where G is Fermi's constant.

Other milestones are placed by Touschek at the points where weak interactions "reach" electromagnetic interactions and strong and electromagnetic interactions become of the same order of magnitude[148)]. The curious thing, pointed out by Touschek, is that all of them appear to be of the same order of magnitude, as if they were part of some superior design, suggested also by the fact that the relationship

$$m_n = \left(\frac{m_\mu}{m_e}\right)^{(n-1)/2} m_e = (206)^{(n-1)/2} m_e$$

seems to be grossly fulfilled; for $n = 1$ one has the electron, for $n = 2$ nothing (?), for $n = 3$ the muon, for $n = 4$ the proton, for $n = 5$ the intermediate boson W, and for $n = 6$ the particle of mass m_G defined above.

Apart from these numerological considerations, I like to recall that Bruno always stressed, as an essential point to be kept in mind in the decisions about the construction of a new accelerator, that its energy should be above a "foreseeable threshold" so that it could open up the possibility of throwing at least a glance over a new phenomenological panorama.

Bruno's influence on his young students and on those who had recently graduated was very marked, even when their interests were not directly those which concerned Bruno at that moment. This was particularly true in the case of Luciano Pietronero, who came into contact with Bruno immediately after graduating in 1971.

Bruno suggested that he should re-examine a classic problem which had been set by Hans Thirring in 1918[149)], but had not yet been fully resolved. As a result of this research, an internal report of the Istituto Guglielmo Marconi had been written with the title: "On rotating reference systems in Einstein's theory of gravitation"[150)]. The manuscript of this report was revised by Touschek when Pietronero paid a visit to Sperlonga, where Bruno was spending several days' holiday in July 1971. Pietronero still remembers the scene with Bruno, his son Francis, and himself sitting at a small table facing the sea, with a bottle of wine, while a record of Viennese cabaret music was being played on the gramophone. On this occasion, as on others, Touschek would amaze his listeners with his brilliant conversation, the speed at which he would grasp the meaning of human situations, like scientific problems, "as if he had an extra gear", to use one of Pietronero's expressions. He would go right to the heart of the problem with extreme clarity, as is also clear from the "Lectures on mathematical methods for students of physics"[66].

Pietronero was convinced that this first paper should also be signed by Bruno, who had helped him more or less directly, but, to his astonishment and embarrassment, Bruno would hear nothing of this. He continued to be interested in Pietronero's work on this subject or related problems, for some time with a substantial direct influence on him[151)], but very soon after allowing him to find his way by himself[152)].

14. THE CRISIS IN THE UNIVERSITY AND RESEARCH LABORATORIES. SOME CULTURAL CONTRIBUTIONS BY TOUSCHEK OUTSIDE THE UNIVERSITY

The protest movement started at the end of January 1968 at the University of Rome and the Istituto di Fisica Guglielmo Marconi. It involved students and even more young people who had graduated in recent years and wanted a change in the university, since the chances of entry were very few. Touschek was deeply moved by the overwhelming majority of arguments adopted by the demonstrators. He was even more disturbed by the views enforced by a small group who assumed the sole authority to understand the situation and the consequent right of taking even violent action against the others.

There were certainly many reasons for the unease in the Italian Universities, but these were always relegated to the second or third place, or were simply overlooked in view of extremely abstract statements of principle, which were almost always borrowed, without any adaptation, from historical or political situations in other countries (USA or France).

As almost always happens in such circumstances, some of the young dissidents, especially during the initial period, were incited by noble and disinterested proposals, even though they were naïve and did not relate to the true situation; but they were immediately followed by all of those who wanted to take advantage of any upheaval in order to have the chance of embarking on a career which was not selective at the outset, and was guaranteed for the rest of their lives. The quality of the persons who, from time to time, assumed the role of leaders of the agitation, and their proposals, worsened over the years, and Bruno, who was extremely sensitive to these changes, became increasingly alarmed.

When, in 1973 or 1974 he was strongly criticized personally by the students, who started to accuse him of being a Nazi, because he tried to maintain a serious tone (even if on occasions this was rather difficult) during his lectures and examinations, he almost completely stopped attending the Institute. He worked at home, where he was joined by his collaborators. It was thus that the paper which he produced in 1974 entitled "What is high energy?" [62], contains the rather polemic reference to the location of the work as: "Garvens S.p.A., Rome, Piazza Indipendenza, Italy".

It was about this time that he finally changed his attitude with regard to Italy. When he settled in Rome, and over all the subsequent years—especially during the e^+e^- ring period—Bruno felt fully at ease in this country. From time to time he was irritated by the red tape necessary when completing some official formality (his application to renew his Italian residence permit, to move his phone from one flat to another and so on), but he felt, and often openly said, that in the physics environment the work was carried out in a receptive framework, which was flexible enough to adapt to rapid changes in ideas, and simplified the implementation of the corresponding programmes.

The first major shock to this view which he had of Italy occurred in 1963–64 as a result of the Ippolito trial[153)], a well-known case which was sparked off by a series of rather superficial articles by Giuseppe Saragat[154)], ending with a verdict which was not only unjust, but also resulted in paralysing the entire Italian bureaucracy, especially in the research organizations. The latter was subsequently further affected by the Marotta and Giacomello cases[155)], which occurred slightly later and for rather similar reasons. There was, in fact, a whole series of extremely serious legal cases, which involved people who had spent many years of their life in promoting the scientific and technological development of our country, to ensure—often with much success—that Italy did not lag behind the other European countries.

The ensuing overall paralysis of the bureaucratic system had also had a serious effect on the new vacancies, and in this way had been one of the elements added to the many other important and justified reasons for the protest.

All of this had dismayed Bruno Touschek, who told me of his disappointment, sometimes expressing his relief that he had rejected the idea, admittedly of short duration, of changing his nationality.

The protest movement in 1971 had also affected the Laboratori Nazionali di Frascati, as was already said at the end of Section 11. As soon as ADONE was ready to operate, a strike prevented its utilization from 30 May to 19 September, and even during the successive months the work was resumed but without the commitment and enthusiasm which the type and performance of the machine deserved.

It was in this climate of a university in the throes of a crisis, and research laboratories which were only half operating, that Bruno Touschek began to take an interest in teaching problems at the high schools.

Another reason was that his children Francis and Stefan, who had attended since they were small the Swiss school in Rome (where the teaching was given in German), had now started to attend high school.

In November 1972, Bruno Touschek attended the second Incontro di Serapo, organized by Giulio Cortini for a group of high school teachers, which, under the guidance of Cortini, had begun to concern itself with the problem of "restricted relativity". After a full day of discussions, at a time when everyone else was going to bed, Bruno sat down at a table in the hotel room, with a bottle of cognac and a glass in front of him, and started to write the "skeleton" of his lectures on relativity. Next morning, he was still writing there, faced by an almost empty bottle and a 25-page manuscript beautifully written, without any corrections.

On his return to Rome, he gave, at the invitation of Professor Lina Mancini Proia a set of four lectures at the Liceo Virgilio on this subject. A few months later (March 1973) he prepared an internal report of the Istituto Guglielmo Marconi on the "Course on restricted relativity" [67], telephoned Professor Piera Salvetti and, after obtaining the necessary agreement, gave seven lectures at the Liceo Mamiani during March and April. In these lectures, he adopted the fairly usual approach of deducing the Lorentz transformation from the invariance of the velocity of light with respect to the reference system, and the essentially linear nature of the relations sought. In Bruno's opinion, this method of deduction had the merit of showing students how a theory is constructed.

The lectures, which were always brilliant, proved highly successful among the students, who found them somewhat difficult but were fascinated by Bruno's personality and liveliness.

Bruno's appointment as a foreign member of Accademia Nazionale dei Lincei, in 1972 (see Section 7), opened up a possibility for him to use his extraordinary energy in another type of teaching activity.

At its meeting on 9 March 1975, the Accademia Nazionale dei Lincei examined and discussed the report submitted by the Commission appointed for this purpose, concerning the possibility of setting up, within the Academy, and as part of the Centro Interdisciplinare di Matematica e Fisica, a "Science Centre", the main purpose of which was to communicate the latest results of scientific work to the widest possible public. The Commission was composed of A. Carrelli, G. Salvini and B. Touschek.

During the discussion, Bruno stated that he was immediately available on a "full-time" basis to set under way the programme proposed by the Commission, arranging a series of meetings with the people who were interested in this idea, so that arrangements could be made as soon as possible for a series of lectures of an "episodic" type. The main feature of these lectures was to demonstrate the "dynamics of science", whilst ensuring a "humanistic appearance". These expressions were used in a circular letter which Bruno Touschek sent on 13 March 1975 and which received enthusiastic response from many people.

In this way, a series of lectures took place, recorded on video tape, under the general title "Study of living science". From that moment, Touschek devoted himself with outstanding energy to producing these lectures, in which he was helped by his son Francis. As can be seen from the names of the speakers and the titles of the lectures[156)], a very remarkable range of subjects was dealt with. In fact, the overall collection represents a "living and permanent document" of the development of many important chapters in physics, which remains in the safekeeping of the Accademia dei Lincei. The lectures proved extremely successful, as was shown from the number of persons who attended, mainly young people, many of whom usually found it impossible to find a seat.

The lecture concerning the teaching of quantum theory [69], which was given by Bruno himself, although very valuable, does not form part of this scientifically and historically interesting set of lectures.

When Bruno Touschek moved to Geneva, at the beginning of October 1977, he was now in poor health, and it was not clear whether he would return to Italy to work and live permanently.

In this post of Visiting Scientist to which Touschek had been appointed, he was to collaborate in the development of the method of stochastic cooling of electron (and proton) beams, as proposed and developed by S. van der Meer at CERN[157)], in preparation for its use in the SPS of CERN (see Table 2).

In reality, Bruno hoped to find a post of professor or research worker in the UK, about which he had often said rather unfavourable things, but, in view of the upheaval in Italy, appeared to be an island of salvation.

After arriving in Geneva, Bruno Touschek had already completed on 16 January 1978 a manuscript on stochastic cooling [63], but its contents were not in keeping with the approach developed at CERN by

Bruno Touschek in Geneva (Hospital of La Tour, 1978)

S. van der Meer and others. Three days earlier, he had called van der Meer from La Tour Hospital and tried to explain the essential point of his paper, but as can easily be understood, this proved insufficient.

This was, however, the last scientific paper produced by Bruno whose health was now extremely poor. As I was told by R. Hagedorn, who frequently went to visit him at the La Tour Hospital, just before he left for Innsbruck, one could not fail to be taken aback by his physical and mental condition.

15. BRUNO'S ARTISTIC BENT AND HIS FINAL CULTURAL INTERESTS

As a researcher, Bruno Touschek struck everyone by the originality of his thinking, the Cartesian clarity of his approach, and his enthusiasm in what he himself or others were doing.

Since the earliest days after his arrival in Rome, Bruno had acquired the habit of knocking on the door of my study at least three or four times a week, when he arrived at the Institute, rather early in the morning on his way to his own study. He would come in and tell me about his latest thoughts, usually those of the night before, concerning the problem which he was concentrating on, or about an interesting result achieved by one of his young pupils and collaborators. His enthusiasm and incisive remarks were extremely stimulating and pleasant to hear. Even when he was talking of scientific problems he would very often introduce a subtle degree of humour, which would emerge from his texts and especially his drawings.

As stated by P.I. Dee (see Section 3), he possessed an unusual skill in caricaturing his surroundings and local customs, which he would draw with a pen on the first piece of paper which came to hand, during the degree examination or Faculty sessions, or during the various meetings of the commissions or working groups dealing with the activities of the Institute or of the Laboratori Nazionali di Frascati.

This skill was a very marked characteristic on his mother's side of the family. She was rather good at drawing and this was even more true of her brother, Oscar Weltmann, a well-known doctor and dilettante painter.

The 24 sketches reproduced at the end of this biography have been taken from a large collection, which friends and relatives gathered from the wastepaper basket or the table where Bruno had left them at the end of a committee meeting or examination session.

One of the "leitmotivs" which is frequently represented is the "self-injury" from which the whole of our society and each one of us, individually, suffers (Nos. 1–3). This disease, which according to Bruno was particularly serious in the Italian university environment, is represented in various ways, such as a man who is planting a nail in his knee or eye or who is firing a gun overhead into the top of his spine.

His caricatural approach, which is often very amusing and sometimes grotesque, is always present, and in certain cases (Nos. 4–10) is the only real purpose of the drawing.

Drawing No. 8 is a caricature of myself, which Bruno drew at the time when, as a result of the Ippolito Case, suspicion was cast on all those who, like myself, had been or were members of the Directing Committee of the CNEN, and had defended the organization and the broad lines which it had followed for many years. Drawing No. 9 illustrates the "superego of the motorcyclist" and therefore also has a self-critical content.

In other drawings (Nos. 11–13) it was the Degree Examination Commission which received the attention of the caricaturist, or it might be one of its members who is playing, rather shyly behind his seat, with a yo-yo, or another member involved in the "hearing of theses". In this instance the improper use of the Italian enhances the inherently comic nature of his drawing.

Other drawings represent typical laboratory scenes: a woman looking through a microscope, embarrassed by the presence of a small fly which is flying around the panel located on the wall (No. 14), and a discussion concerning the direction of the magnetic field on the basis of the "three-finger rule" (No. 15) which Bruno drew on a page of the record of measurements made with AdA at Orsay (see Section 9), during the Symposium on Storage Rings held in that laboratory from 26 to 30 September 1966. This drawing was printed in the proceedings of the symposium as the initial page of the session on "Magnetic Detectors — Radiative Corrections".

Further drawings (Nos. 16–19) concern the life at the Faculty of Mathematical, Physical and Natural Sciences: the contempt of the Council of the Faculty for an article of a recent law or a ministerial circular (No. 16), the decision taken by the chemistry professors who, failing to reach agreement on which of them should be proposed as Director for all of the chemical activities performed at their department, had decided to keep the single-professorship institutes (No. 17), and the disagreements which arose at a certain moment among mathematical colleagues (No. 18). Drawing No. 19, concerning the introductory nature of the courses attains the heights of efficiency in its schematic symbolism.

Still other drawings (Nos. 20–22) concern the period of the protest movement (1968–1976). No. 20 represents an "assembly" in the large hall of the Istituto di Fisica Guglielmo Marconi. No. 21 represents a group of unidentified persons who wanted to enter the Institute which was occupied by the "students", at the time when Giorgio Careri was Director of the Institute (1968–70), and was therefore accused, by all of the factions, of extremely serious and absurd failings and problems of management. No. 22 shows the discussion for the choice of the Director of the Istituto di Fisica Guglielmo Marconi, which Bruno Touschek had renamed "Istituto Maria Montessori", to stress the attitude taken by a part of the teaching staff, whose only thought was to allow the students to do whatever they wished. The symbol CB stands for "Carlo Bernardini".

Drawing No. 23 is an example of drawing which contained a fundamental contradiction, and No. 24 is an example of those based on the merging of two different concepts or objects. In this case the combination was between a lynx, which is the emblem of the Accademia Nazionale dei Lincei, and the six-legged dog, symbolizing the Ente Nazionale Idrocarburi.

Some of these drawings recall those of Egon Schiele (1890–1918) who, together with Gustav Klimt (1862–1918), an admirer of and sometimes inspired by oriental art, was among his preferred painters. These artists of the Viennese Secession had always attracted him by their culture and sensitivity, as well as by their almost sickly refinement, but this attraction grew immensely in the final months of his life. When he was in Geneva, in autumn 1977, he had purchased from somewhere or other a batik[158)] by a Java painter. It bore geometric designs, with strong and at the same time dark colours, giving a decorative pattern, which is somehow reminiscent of certain decorative paintings by Klimt, rather more because of the differences than certain remote resemblances.

Talking with Valentino Braitenberg, who had visited him in Innsbruck a few days before his death, Bruno expressed the desire to read a biography of Ludwig Wittgenstein[159)]. He had noticed, he said, in himself a desire of identification with the philosopher, his fellow-citizen, perhaps due also to the already remote readings of logic he had made at the gymnasium in Vienna. He had the impression of having neglected the more general aspects of knowledge. Valentino, however, did not succeed in providing him in time with the Wittgenstein biography.

It was in the final phase of his life that it became easier for his Italian friends to grasp the profound reasons for his enthusiasm for *Das Glasperlenspiel, Versuch einer Lebensbeschreibung des Magister Ludi Josef Kneckt* by Hermann Hesse (1877–1962)—his enthusiasm for this Utopia in which the various figures fluctuate between a real and symbolic existence, in an imaginary future country, where, in about two centuries, mankind has succeeded in overcoming the present world and society, characterized by frequent wars, by wild individualism and by a culture reduced to "feuilletons", that is to the "third page" ("potted culture" page) of the newspapers. The new society is guided, morally and culturally, by an intellectual aristocracy, which, through the study and meditation, always deeper, of the form and contents of music and mathematics in all their aspects, has succeeded in producing a new order, which, at the end, reveals itself to be without a way out, based on a game, extremely refined but sterile, like so many others.

At the hospital, first in Geneva and later in Innsbruck, Bruno read with great interest books on history and literature, mainly those regarding the Viennese life of the beginning of our century, and specially concerning the books of Karl Kraus (1874–1936)[160)], and on Karl Kraus[161)] and Gustav Klimt[162)].

Karl Kraus had been always his favourite author: Kraus had founded, in 1899, the review *Die Fackel* which he wrote virtually unaided for some 37 years, hinting at the pending collapse of the Habsburg Empire, satirizing the monstrous day-to-day events, and putting to shame the police chiefs who had committed murder, as well as the criminal financiers.

Kraus' famous aphorisms[163)] were probably the source of Bruno Touschek's paradoxical expressions or remarks. In the 1950's and 1960's he would often refer to his country of origin in scathingly critical terms. However, on reaching the end of his life, he seemed to find rest and contentment only by re-immersing himself in the culture of that Viennese and partly Jewish atmosphere of the beginning of the century, which had been his background and had so profoundly affected his youth.

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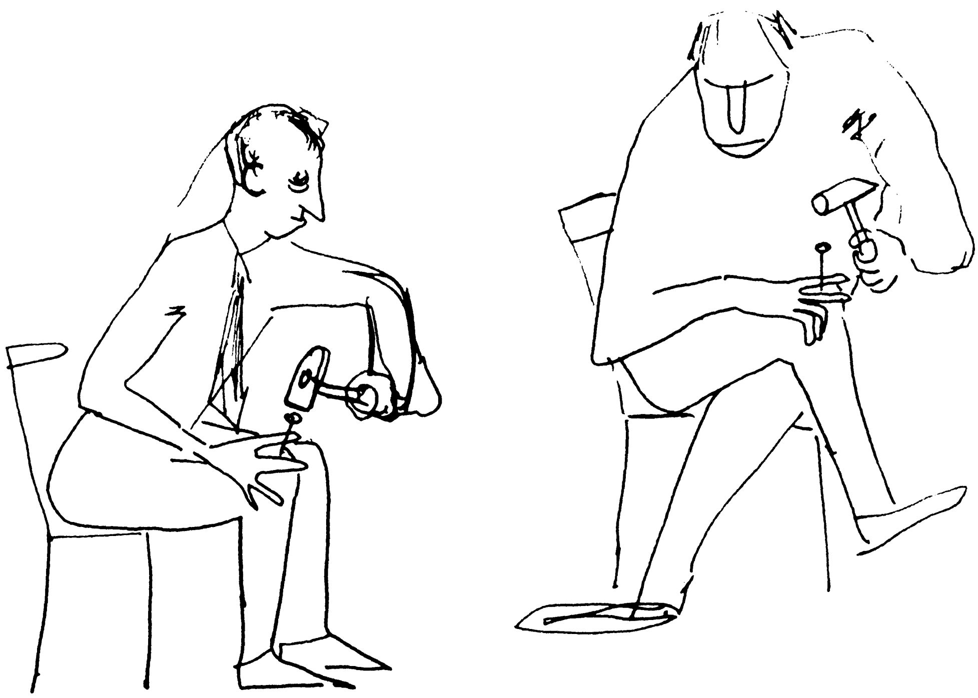

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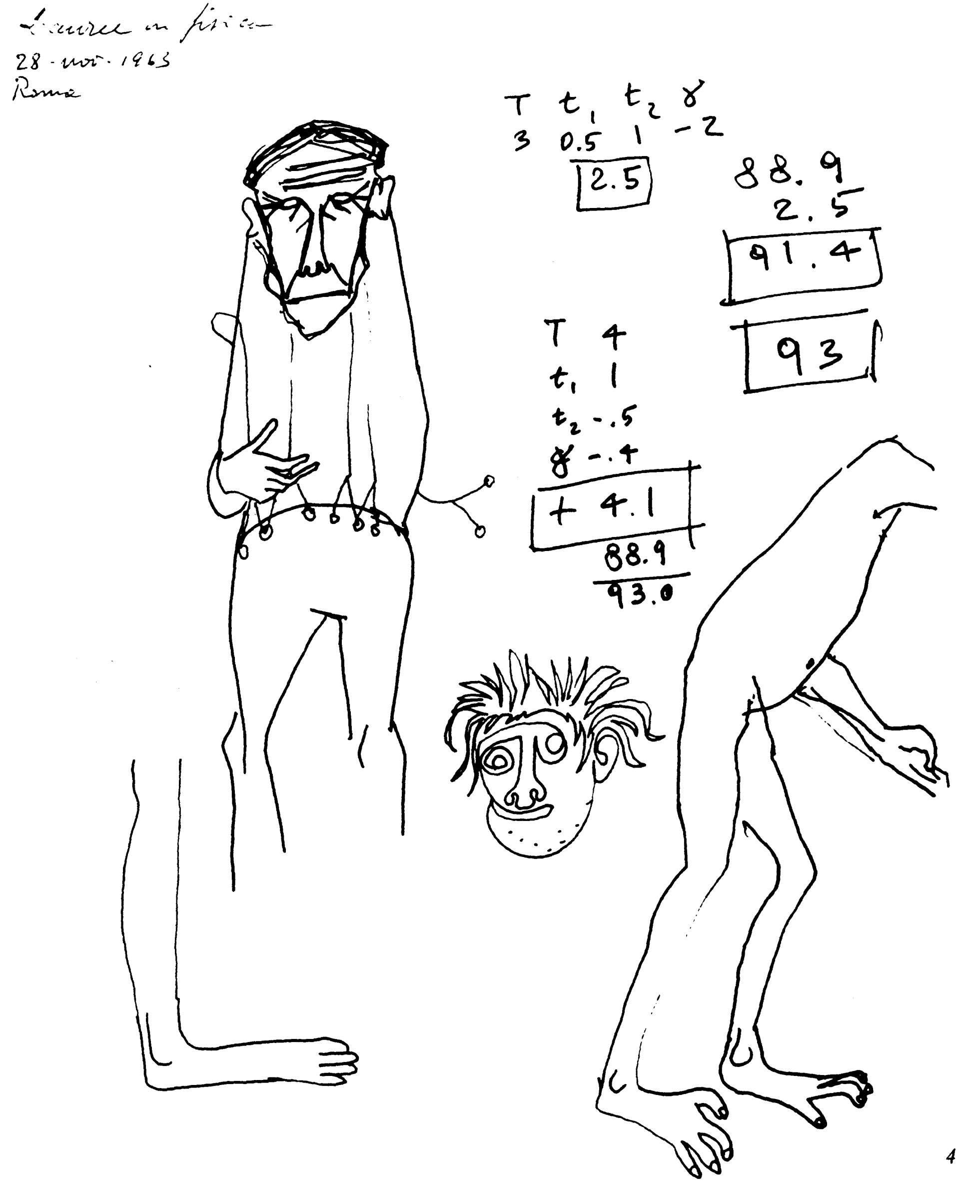
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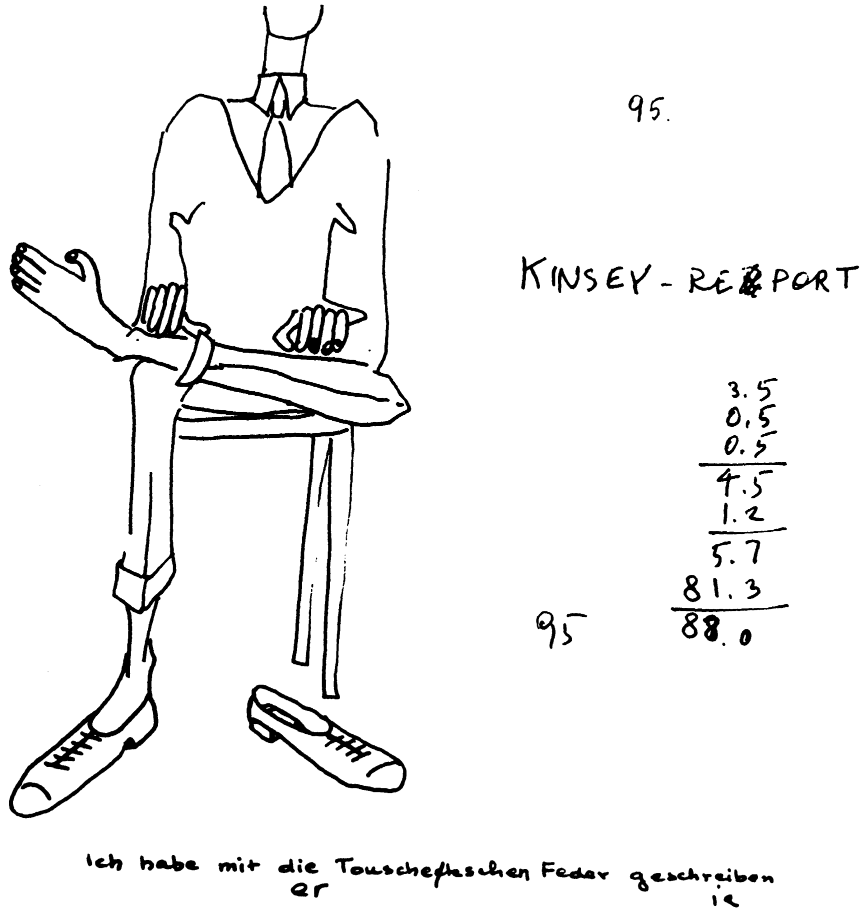
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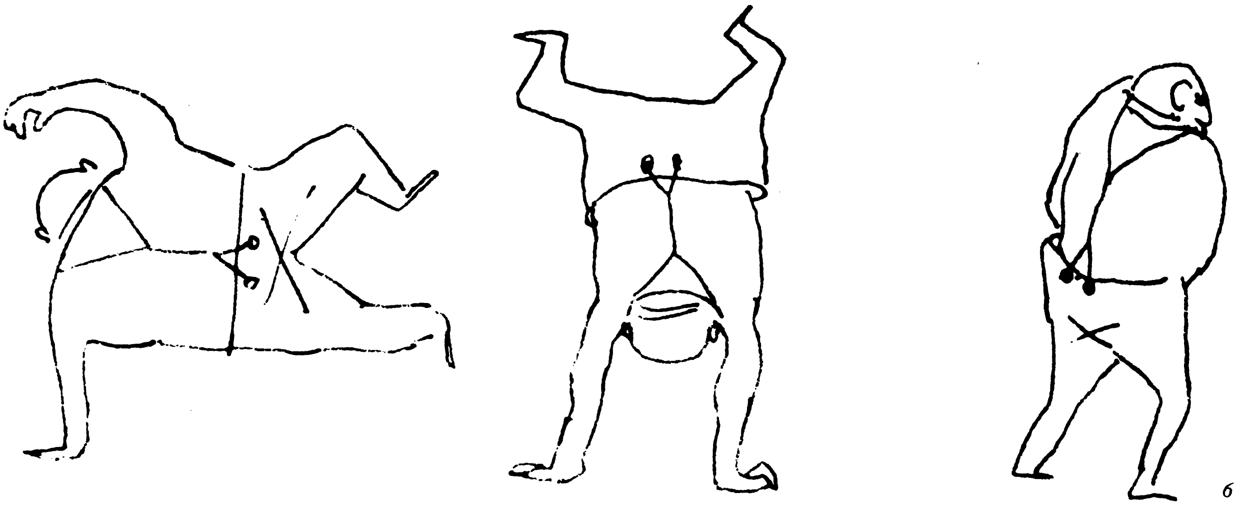

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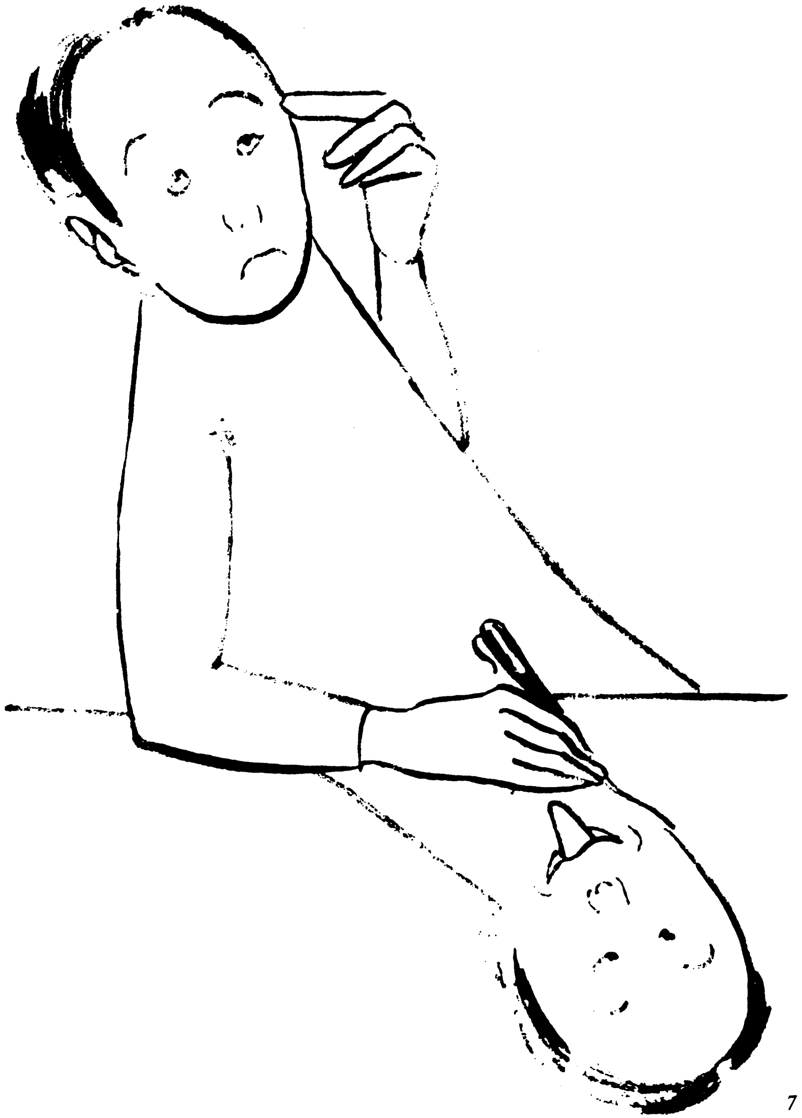

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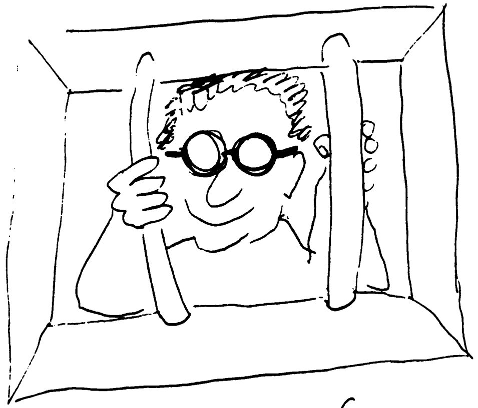

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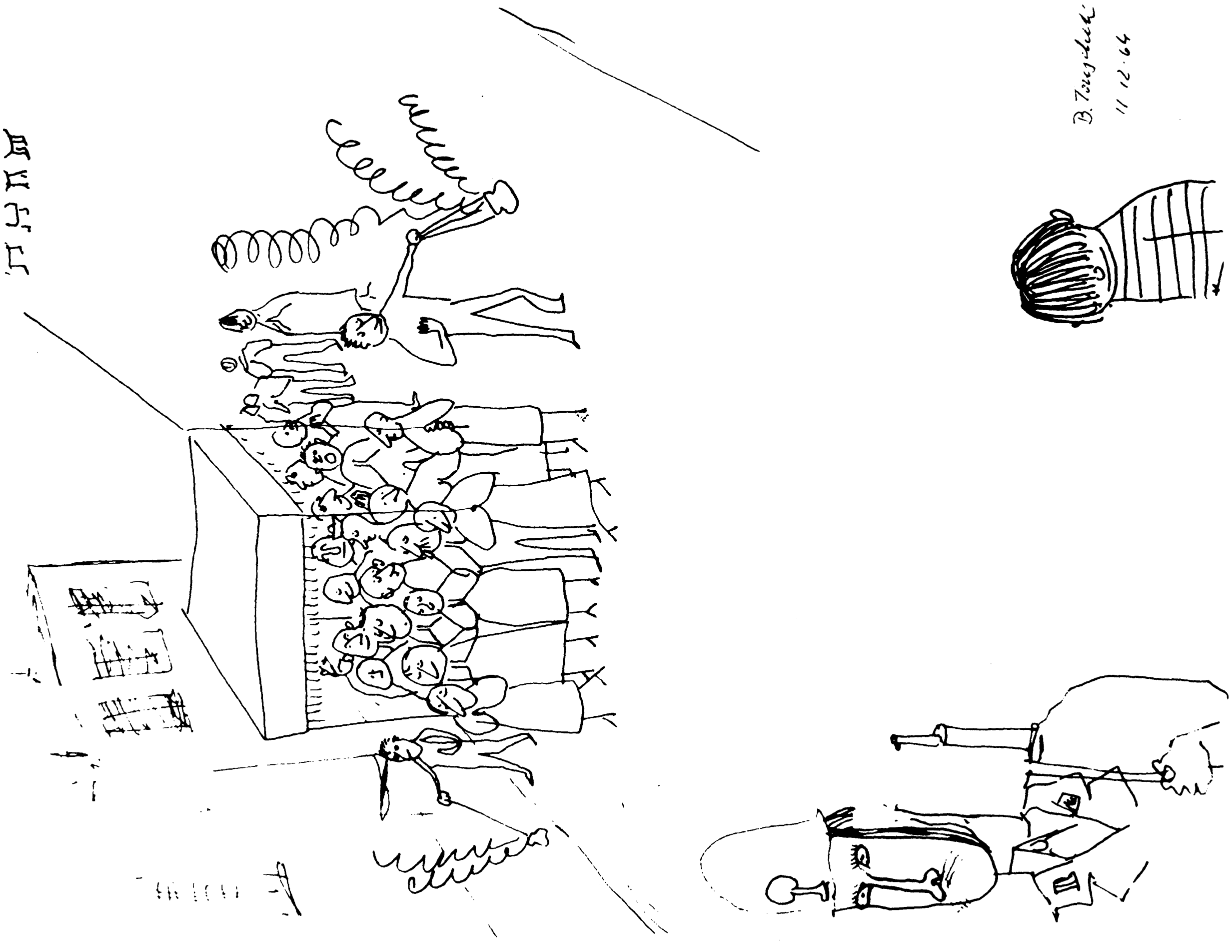

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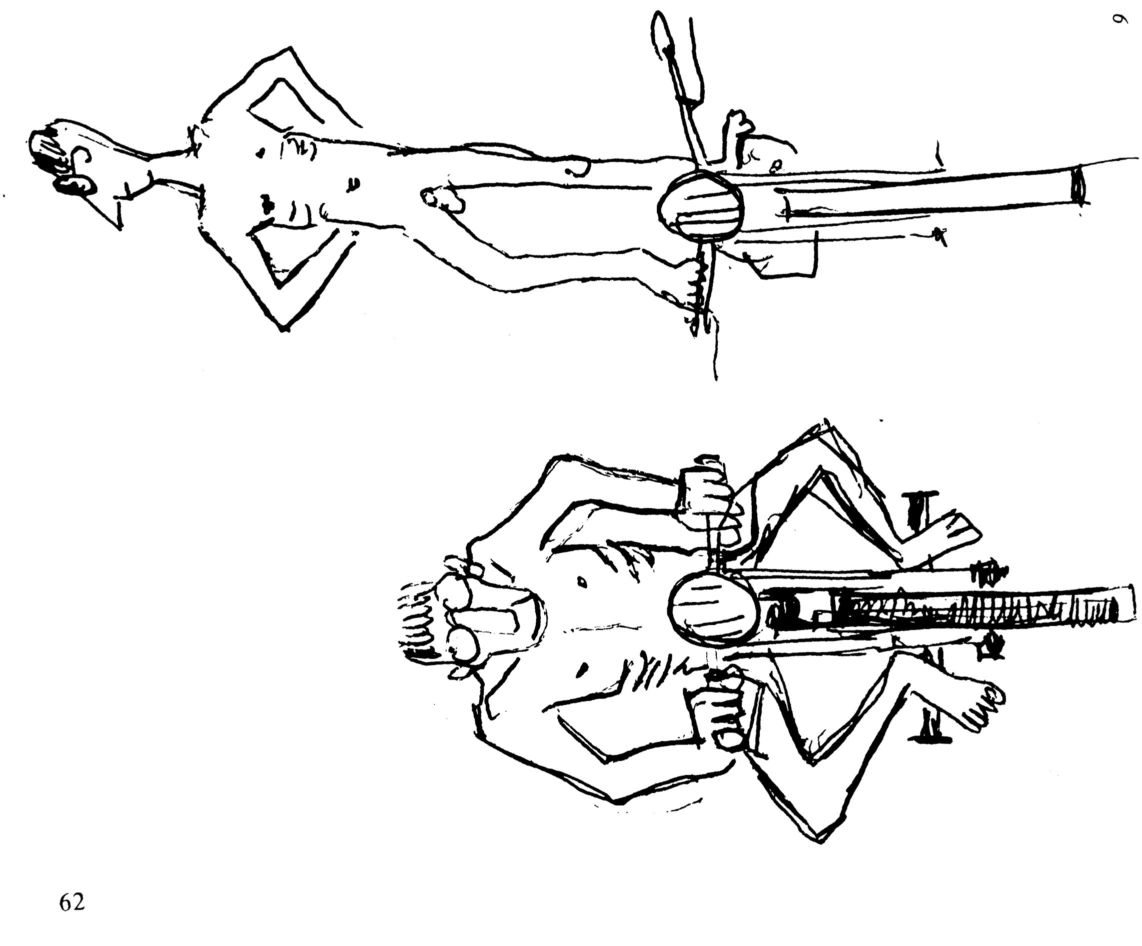

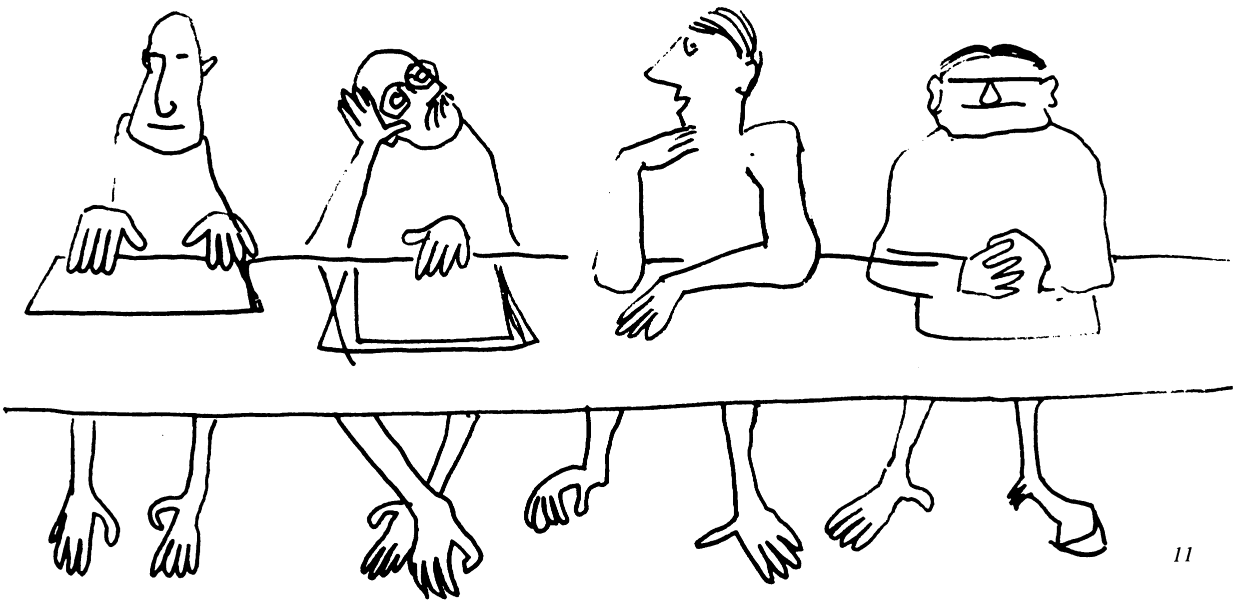

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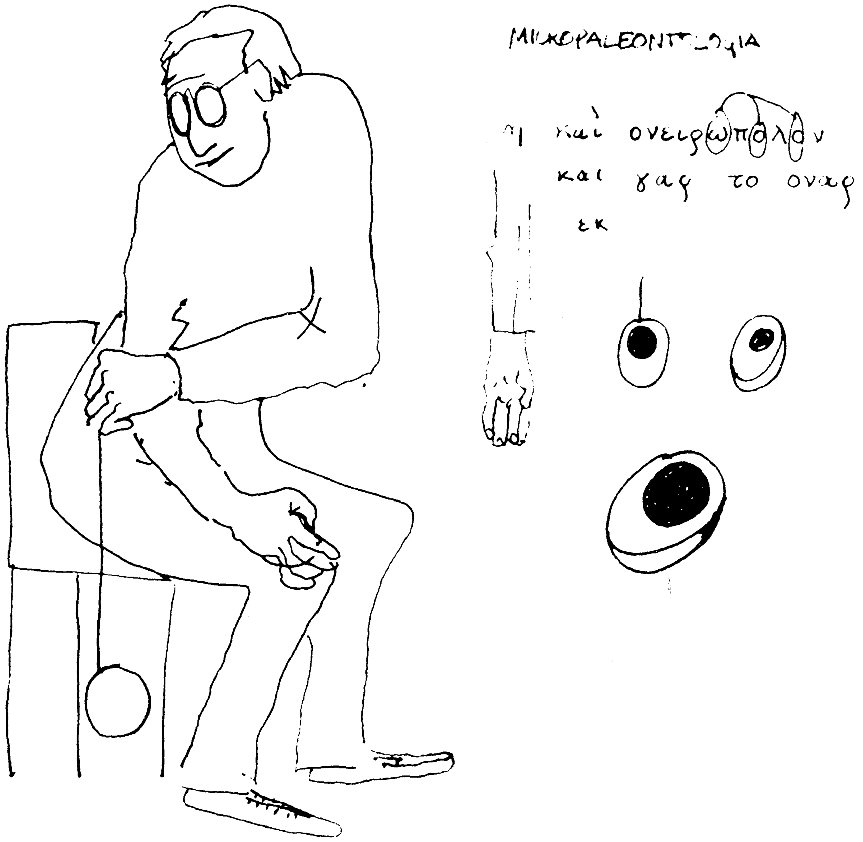

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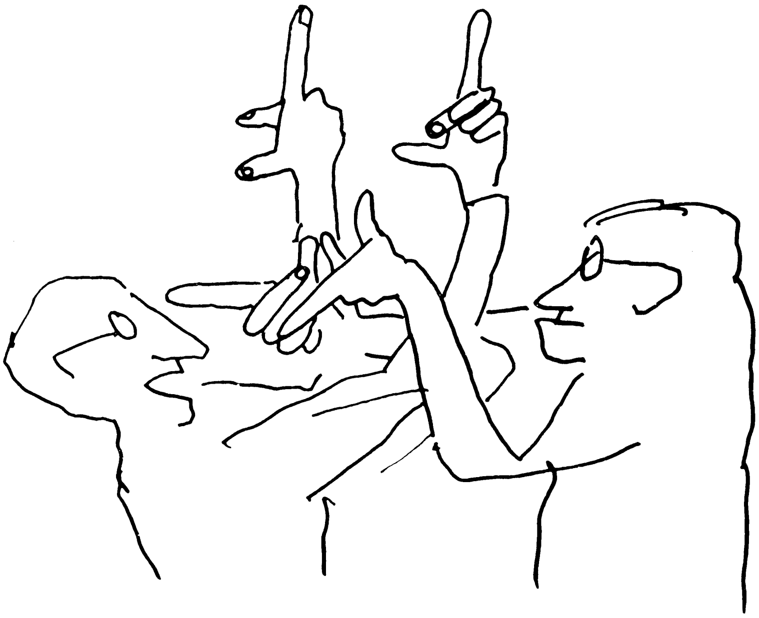

MAGNETIC DISCUSSION

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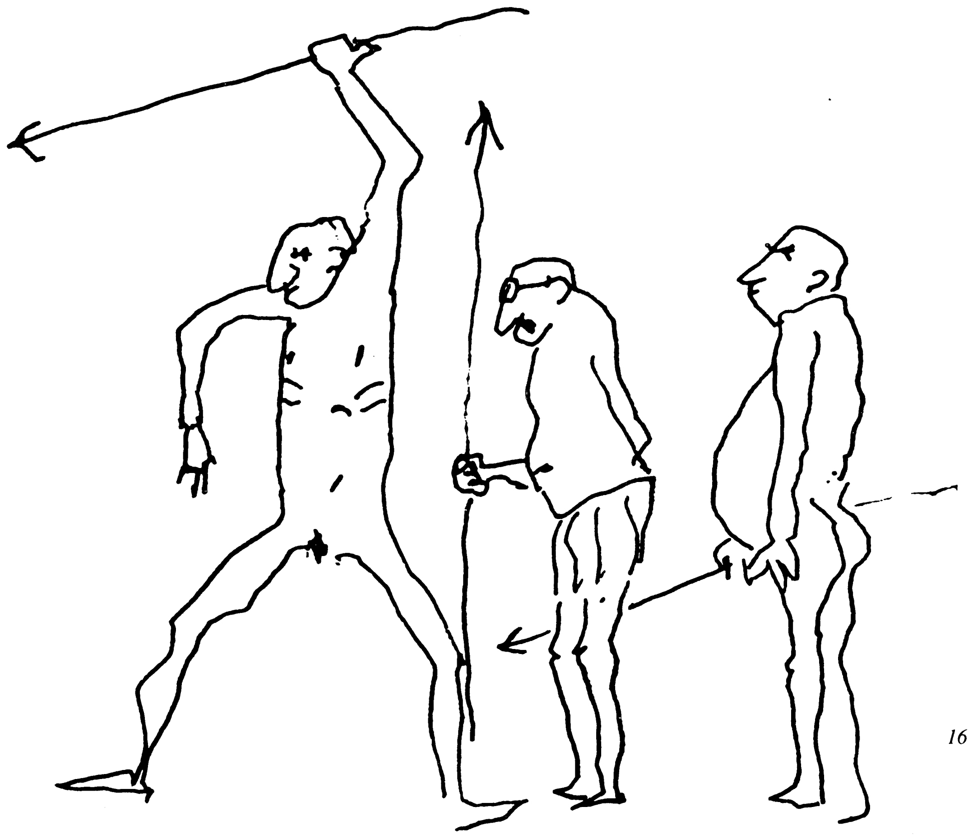

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