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Inertial Systems

One of the fundamental concepts of special relativity is that of the inertial reference frame, also referred to as inertial reference system or just inertial system. The terms "frame" and "system" are synonymous in the context of the theory and are not to be primarily thought of as something structurally complex. The two essential characteristics of an inertial system in the Einsteinian scheme are its ability to serve as a point of origin for Cartesian co-ordinates and its inertiality. Other characteristics are of lesser importance. The reference point function is undoubtedly the principal feature of the Einsteinian inertial system, and it places the system more in the realm of analytical geometry than in the realm of physics. This is quite in accordance with the Einsteinian principle of mathematical pre-eminence which leads to inflated significance being attached to features of mathematical nature. The second attribute, inertiality, is a basic property ascribed to all physical bodies in Newtonian dynamics and associated with their mass.

Einstein's initial ideas of what was later called the special theory were contained in the *kinematical part* of his 1905 paper. Kinematics is a branch of mechanics which deals with the geometrical description of mechanical motion. It examines the configuration of motion, and this includes rectilinear as well as circular motion, but it disregards causes. Kinematics is based on geometrical points, which symbolise mechanical bodies, velocities and accelerations. It deals with space and time, but not with mass and its associated concepts, such as inertia, momentum and force. In the *kinematical part* of the 1905 paper Einstein, starting from two postulates and using kinematical arguments, attempted to demonstrate the untenability of the Newtonian concept of absolute time as a consequence of relative motion. But he did not elaborate or analyse the wider implications arising from his interpretation of relative motion. These implications became clear after the publication of his 1905 paper, and as a result the kinematics of Einstein's theory had to be restricted to uniform and non-accelerated motion and the corresponding dynamics to strictly inertial phenomena.

One of the difficulties of Einstein's kinematics is that its relationship with dynamics, and that means Newtonian dynamics, has never been elucidated. Although there is an important difference between dealing with geometrical points in kinematical terms and the material points of dynamics with their involvement of inertia, momentum and force, Einstein never acknowledged this difference and never made any effort to explain how his kinematical theory and Newtonian dynamics fit together. He saw no reason to distinguish kinematical and dynamical statements. For instance, when Einstein says: *Let us take a system of co-ordinates in which the equations of Newtonian mechanics hold good,* he must be criticised. Newtonian mechanics does not hold good in systems of co-ordinates, but in systems based on mass-points. Co-ordinate systems are secondary and theoretical structures erected on mass-points. For some people the Einsteinian shift of emphasis may not appear significant, but in fact the quoted phrase is placed at the beginning of the *kinematical part* of the 1905 paper and determines the subsequent direction of the discussion.

Einstein prefers to talk in terms of reference frames and co-ordinate systems, and even attaches observers, rigid rods and clocks to them, but we are never told in what way or to what extent these frames and systems are similar to material points or to physical bodies with a substantial volume of mass. It appears that sometimes geometrical points and mass-points are equivalent and sometimes they are not. This produces an undercurrent of imprecision and ambivalence in relativistic arguments. The plain fact is that we do not encounter Cartesian co-ordinate systems in the physical world and even less observers mounted on the intersections of co-ordinates. The question as to how the point of origin of co-ordinates is to be determined in concrete physical situations as well as in Einsteinian imaginary trains and lifts has no simple answer and is by no means unimportant. A conventionally chosen reference point, the geometrical centre of a body chosen as a reference frame, the centre of mass of a body and the centre of a gravitational system do not necessarily coincide. Some points are difficult to establish, some are subject to change. Reference points are selected because they are physically easy to determine and not because they are centres of inertial systems. Mass and gravitational centres are hidden and subject to fluctuations and intrinsic uncertainties. Einstein disregards the fact that a terrestrial observer, for instance, is 6300 km away from the point of origin of the co-ordinates of his "inertial" system and that his line of vision is not identical with the geometrical line originating from the centre of his reference frame.

Relativists refer to the mathematical formalism of the theory as a guarantee of rigorous exactitude, but they do not worry about the uncertainties in the physical basis of their formalism. Has Einstein ever tried to consider real physical bodies in his theory? His preoccupation with the geometrical formalism of a restricted kinematical problem hides the unpleasant fact that any motion, and this includes relative motion, is meaningless without the concept of mass and aggregates of mass, and in particular without Newtonian absolute space and time. Inertial systems in relative motion cannot be thought of without real bodies, rigid space and constant time-flow. These three are absolutely necessary prerequisites.

In Newtonian dynamical theory the notion which is equivalent to the geometrical point in kinematics is the mass-point, an idealised physical body whose mass can be thought of as concentrated in one point. This mass-point, according to Newton's first law of motion, is endowed with a property called inertia. Inertiality is manifested by the ability of the mass-point to remain at rest, if it is at rest, or to remain in uniform rectilinear, i.e. non-accelerated, motion, if it is in uniform rectilinear motion, provided that it is not acted upon by a force. Motion of a mass-point not acted upon by a force is called inertial motion. Physicists do not know what a force is in itself, and a satisfactory definition of the concept is not available. In a circular manner, a force is described as a cause producing a change in the state of rest or in the state of motion of a physical body. In any case, the concept of force need not concern us in detail as it is not an essential ingredient of special relativity.

Einstein does not reject Newton's understanding of inertiality which includes the startling proposition that a body in motion, left to itself, will continue its motion for ever. However, Einstein introduces the additional assumption that there is no finality in the distinction between rest and motion. We are, in principle, unable to determine whether an inertial system is at rest or in motion because, apart from inertial systems, there is no external or superior reference frame. Einstein then makes a further, far-reaching assumption, namely that we are dealing not with a technical inability, but a fundamental ontological and physical condition. There is, in an absolute sense, no distinction between rest and motion. This means that if there are two inertial systems in relative motion to each other, we cannot ascribe rest or motion with any finality to either of them. For descriptive purposes the words "stationary" and "in motion" may be used in relation to the two inertial systems, but the words have no real meaning. Only the concept of relative motion is real. This is the way the Einsteinian world is structured.

The assertion that our inability to distinguish rest from motion is absolute, and that we can do nothing about it, reflects a personal view of Einstein. He poses a problem which may not necessarily be one, and then "solves" it by suggesting an axiomatic proposition which is not associated with any physical evidence and not supported by any rational argument. There is no need to be dogmatic. Our present knowledge of the macro-structure of the universe may well be incomplete, and insufficient to draw precise conclusions about the motion of the Sun and stars. But this is hardly a matter of great importance, and one requiring final judgments at this stage. And our deficiencies may, of course, be rectified in the future.

A theoretical difficulty is raised by Einstein's kinematical and abstract treatment of the fundamentals of motion and the consequent irrecognisability of inertial systems. The special theory proceeds from geometrical points and velocities. The relative velocity between two points may be uniform, but this does not mean, in the absence of other criteria, that inertial motion is taking place. It could just as well be non-inertial motion compensated in such a way that the resulting relative velocity has the same appearance as that of inertial motion. How does the relativist decide, using the tools of his theory, whether an inertial motion between two points is real or apparent? He has no means to decide it. His theoretical framework precludes him from knowing whether he is dealing with inertial motion or not, and this means whether his theory is applicable or not. The non-relativist may well prefer the option that relativity, in relativity's own terms, is inapplicable.

The notion of the inertial system is suffering from a lack of substance, conceptually and physically. Whichever way one looks at it, it remains a geometrical point, an emasculated and functionless apparition. This ghost without a body, imprisoned within the confines of kinematics, has neither place nor purpose in the world of real things. It has not acquired any recognition in practice and its application is limited to hypothetical and fictional situations.

The absence of empirical content in the relativistic model and its complete inconsequentiality become fully apparent when we try to find specimens of inertial systems in the real world. Einsteinianism maintains that in nature we are confronted with a set or class of systems characterised by strict inertiality and forming what cannot be anything else but an ultimate hierarchical level of physical existence. Is there any evidence of such class of systems? Can we point to something in the cosmos complying with this supposition of relativity? In order to find an answer to these questions we must look at the structure of the world. It is not difficult to discover that in terms of increasing structural complexity and dynamic relationships possibly four hierarchical or systems levels have to be considered: the sub-planetary, planetary, solar and galactic level. On which of them do we find the ultimate inertial systems?

The sub-planetary level is represented by separately moving entities in our immediate environment on the surface of the Earth. Does anything in this environment, or in the terrestrial domain generally, qualify to be regarded as a set of inertial systems? The answer must be negative, and not only because the whole Earth is obviously one integrated functional system, but because its mass aggregate with its gravitation precludes any inertiality in the sub-planetary domain.

Perhaps the Earth as a planet is a member of the set of inertial systems? Again, the answer must be negative. Neither the Earth nor any other planet can be an inertial system, because planetary orbits are determined by the gravitational field of the Sun and the resulting motion is not uniform and rectilinear.

The next hierarchical level distinguished in astronomy is that of stars of which the Sun is one. The nearest star to the Sun is named Alpha Centauri and its distance is assumed to be 4.3 light years. According to the attestations of astronomers both stars are moving circularly within our local galactic system, a disc-shaped rotating collection of stars and other astronomical objects whose diameter is of the order of 100,000 light years. If we accept the evidence that the Sun and other stars are executing circular motions in the Galaxy, we are not entitled to regard them as inertial systems.

Finally, we come to the group of astronomical objects known as galaxies or galactic systems. These systems are considered to be large-scale aggregates of stars similar to our own Galaxy, but they are so far away that they have a star-like appearance and are indistinguishable from ordinary stars without the use of instruments. One of the nearest galactic systems to our Galaxy is the Andromeda Nebula. The distance to the nebula is assumed to be several million light years. Astronomers know next to nothing about any individual or relative motions of galactic systems, but it is possible that they move generally away from each other. This view is based on a consistent pattern of red-shifts observed in their spectra. The most plausible explanation of the red-shifts is that an expansion of the universe is taking place. Are galaxies Einsteinian inertial systems? If anyone is determined to favour this view, there is no point in remonstrating with him. The data are not there and the whole argument has no practical meaning. The red-shifts and the distances of millions of light years do not really provide a favourable milieu for proving that relativity works somewhere out there. What sort of conclusions could possibly be drawn from our motion relative to phenomena a two-way communication with which by light signals would require millions of years? It would be far better to admit that there is no empirical evidence of the existence of inertial systems.

That there cannot be a class of strictly inertial systems follows also from theoretical considerations. We are permitted to imagine only one mass-point or mass aggregate, but not two. If there are two separate bodies, or more than two, they will exert a gravitational influence on each other. The influence may be minimal, but it is not non-existent. In principle, therefore, the presence of more than one mass-point excludes the possibility of strictly inertial motion.

Most relativists concede that pure inertial motion cannot be found in nature. But, they say, there is near-inertial or quasi-inertial motion. Quasi-inertiality is then said to be equivalent to inertiality and the seal of approval is given to use it as a substitute wherever the theory of relativity specifies pure inertiality. The adherents of this view argue, for instance, that the orbital motion of the Earth, although clearly not inertial, can nevertheless be equated to inertial motion from the point of view of a terrestrial observer. And the same applies to the rotation of the Earth. It is true that the majority of physical processes in our environment on the surface of the Earth remains unaffected by the two motions of our planet. But this is due to the high uniformity of the acceleration and to the negligible effects of centrifugal forces. We are permitted to speak of quasi-inertiality only in respect of the two motions of the whole Earth through space and without invoking any concept of relative motion unless this motion is in relation to an assumed absolute rest frame in the Newtonian sense. In particular, quasi-inertiality is inapplicable to any separate motion within the terrestrial domain because of the all-pervading gravitation of the Earth. After all, if we throw a stone in the air, it does not continue to move in a straight line for ever. Its velocity and trajectory will be immediately and substantially modified by air particles and gravitation. Quasi-inertiality on Earth is therefore of strictly circumscribed nature and of no relevance to relativity. There is also nothing within the Solar System as a whole which has any similarity with inertial motion between two systems as demanded by relativity.

It is hardly worthwhile to pursue the question of quasi-inertiality of stellar and galactic motions. We simply do not know enough about them and their causes. We are not able to measure the distance between the Sun and the nearest star, Alpha Centauri, with any accuracy, let alone make observations which would help us to resolve problems concerned with relative inertial or quasi-inertial motion. And it is highly improbable that our inability will be overcome in the near future.

One cannot help feeling that Einstein is fighting windmills when he implies that physics is in great danger because it clings to the unprovable idea of an absolute reference frame. This idea has done no harm to physics. There are no intrinsic or practical difficulties in adopting, by convention, a sufficiently comprehensive near-absolute reference system as a universal inertial rest frame, if and when such fundamental frame is really necessary. According to Einstein it does not matter, anyway, whether a system is considered at rest or in motion. If this is so, what is stopping us to assume, for instance, that the network of stars and galaxies as a whole is sufficiently stationary and that the Solar System moves in relation to this network. This assumption would make relativity unnecessary. If and when it is challenged by an extra-solar observer, we could re-consider our assumption. But since there is no evidence of any extra-solar observers we would be wise not to worry about them. In the meantime the stellar network would serve us, despite local displacements of individual stars, very well as a fundamental reference frame and satisfy our practical needs.

It is said that although inertial or quasi-inertial systems cannot be readily discovered in nature and experimented with, it does not follow that they do not exist or that they cannot exist, and that the study of relationships between them has no significance in physics. It is pointed out, for instance, that they could be made artificially. Man-made quasi-inertial systems could be of two kinds: (a) Earth-based installations in which the effect of gravitation is counter-balanced, and (b) space vehicles operating independently in an area of low gravitational intensity. Contemporary technology has, of course, already made some progress in this direction. But this development is not necessarily one which will fill the hearts of relativists with joy. The agencies dealing with astronautics have been using Newtonian physics and have taken remarkably little notice, if any at all, of Einstein. Inertial guidance systems are living proofs that an observer in free space has no orientation problems. He knows where he is coming from and going to, and whether his space ship is moving uniformly or not. The system of fixed stars is successfully used as an inertial rest frame. All this is very un-relativistic, and there is no reason to assume that man-made devices and space travel will contribute any evidence to support relativity.

All considerations about quasi-inertial conditions and systems will not alter the plain fact that quasi-inertiality is an unrealistic and highly unsatisfactory notion. It lacks precision. Those who promote it do not specify how much deviation from strict inertiality is permissible, under what circumstances and why. It introduces an unhealthy arbitrariness in any scientific discussion of claims made on behalf of special relativity and makes them practically incontestable and unfalsifiable. And we are never told why quasi-inertiality, which cannot be distinguished from non-inertiality, should be acceptable when the theory professes to be mathematically exact and quite clearly endowes inertial systems with an absolute status, and when it demands pure inertiality in order to be consistent and valid.

When we concentrate our criticism on the relativistic concept of inertiality, we must not forget that the other ingredient of relativistic inertial motion, namely relative uniform and rectilinear motion, is by no means an empirically recognisable and acceptable concept. In fact, the absurdity of ascribing any fundamental significance to relative rectilinear motion between two systems in the physical world can be demonstrated by the following reasoning. Let us assume that two genuine Einsteinian systems are receding from each other. As time goes by their distance will tend to become infinite. If they are approaching each other, they will collide. In the first instance relativity seems to be a theory of irrelevance, in the second a theory of doom. Furthermore, in the second case gravitational attraction must become significant. At what stage would the two systems cease to be inertial or quasi-inertial systems and become one gravitational system? If we go backwards in time, we must conclude that the two receding systems have been one in the past, and that the two approaching systems must have come from infinity. In both cases a plausible explanation of the origin of Einsteinian rectilinear motion is required, and in the second case also an answer to the question: what is relative infinity?

If the persistent claim of relativity that it is a physical theory is to be taken seriously, it must offer a physical explanation of the concepts with which it operates and to disclose how such fundamental things as inertial systems and rectilinear motion are to be detected in the real world. If this explanation is not forthcoming, it must be concluded that there is no basis for the claim that the theory belongs to physics. The theory depends entirely on inertial frames in relative motion, but why they are elevated to a privileged class in nature when there are no empirical reasons and when the theory is supposedly aimed at abolishing privileged classes of objects remains a complete mystery. Answers to many pertinent questions are not provided. The best we can do is to assume that inertial systems are an imaginary category whose function is to serve as a point of departure for further metaphysical theorising.