Lecture 21
Einstein's Definitions of Position and Time

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Albert Einstein

1879: Born in Ulm, Germany.

1900: Graduated from Zurich Polytechnic

1902: Patent examiner in Bern, Switzerland

1904: This photograph taken

1905: Published 5 revolutionary papers in physics

1955: Died in Princeton, NJ.

Definition (125)

Consider a coordinate system in which Newton's mechanical equations are valid. To distinguish this system verbally from those to be introduced later, and to make our presentation more precise, we will call it "the rest system."

- A "coordinate system" consists of three perpendicular axes.
- "Newton's mechanical equations" are his laws of motion, including the first: bodies not acted on by any force remain at rest or continue in a straight line at constant velocity.
- Newton asserted these laws for a coordinate system at rest in absolute space. But if they hold for one system they also hold for any system moving in a straight line with constant velocity relative to the first. Einstein allows any one of these to be called "the rest system."

Definition of position

Definition (125)

If a particle is at rest relative to this coordinate system, its position relative to the latter can be determined by means of rigid measuring rods using the methods of Euclidean geometry and expressed in Cartesian coordinates.

- "Rigid measuring rods" are ones that don't expand or contract or bend.
- *Procedure:* Lay a rigid measuring rod along the x axis a suitable number of times, then lay it parallel to the y axis a suitable number of times, then parallel to the z axis; make the number of times each way be such that you end up at the particle. The particle's coordinates are the number of times the measuring rod was laid out in each direction.

Definition of time

Definition using one clock (125–26)

- It might seem that all difficulties in the definition of "time" could be overcome by substituting "position of the small hand of my clock" for "time." Such a definition is indeed sufficient if a time is to be defined exclusively for the place at which the clock is located; but the definition is no longer satisfactory when . . . events occurring at places remote from the clock have to be evaluated temporally.

- To be sure, we could content ourselves with evaluating the time of events by stationing an observer with a clock at the origin of the coordinates who assigns to an event to be evaluated the position of the hands of the clock when a light signal from that event reaches him through empty space. However, we know from experience that such a coordination has the drawback of not being independent of the position of the observer with the clock.

Einstein's definition of time will use synchronous clocks.

Definition of synchronous clocks (126)

- Suppose there is a clock at point A and another clock at point B. Let a light ray be sent from A to B, then reflected back from B to A. Let
  t_A = Reading on the clock at A when the ray leaves A.
  t_B = Reading on the clock at B when the ray arrives at B.
  t'_A = Reading on the clock at A when the ray returns to A.
- *The two clocks are synchronous by definition if*
  $$t_B - t_A = t'_A - t_B.$$

Explanation: For synchronous clocks,

- $t_B - t_A$ = the time light took to travel from A to B.
- $t'_A - t_B$ = the time light took to travel from B to A.

Einstein assumed light takes the same time each way, so if the clocks are synchronous then $t_B - t_A = t'_A - t_B$.

Einstein's definition of rest-system time (127)

- *The "time" of an event is the reading obtained simultaneously from a clock at rest that is located at the place of the event, this clock being synchronous … with a specified clock at rest.*

- *We have defined time by means of clocks at rest in the rest system; because the time just defined is related to the system at rest, we will call it "the time of the rest system."*

Exercise

There has been a murder on the Orient Express as it was speeding through Turkey. How could you determine the time of the murder, if the "specified clock" is at rest in Urbana?

1. What did Einstein mean by "the rest system"?

2. What procedure did Einstein envisage for determining the position of a particle at rest in the rest system?

3. Einstein said: "It might seem as if all difficulties involved in the definition of 'time' could be overcome by substituting 'position of the small hand of my clock' for 'time'." Under what circumstances did Einstein think this definition is (a) adequate and (b) inadequate? What is the reason for the difference?

4. State Einstein's definition of what it means for clocks at different places to be synchronous.

5. How did Einstein define the rest-system time of an event?

📄 Albert Einstein.
On the electrodynamics of moving bodies.
In John Stachel, editor, *Einstein's Miraculous Year: Five Papers That Changed the Face of Physics*. Princeton University Press, 1998.
Numbers in parentheses are page numbers of this edition.
I have corrected the translation in some places.