Title: Special Relativity - Part 2

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Abstract:

Special relativity: Physics of the very fast

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Summary

- The two postulates of special relativity
- Journey into the fourth dimension …

What is special relativity

- Let us begin with motion in everyday world around us.

  Eg. a hockey puck sliding across the ice,
  A car travelling along a straight highway at 60 km/h
  A spaceship floating through space at a constant velocity

- What theory do we use to understand what is happening in these cases?
  Newtonian mechanics. Eg. for every action there is an equal and opposite reaction, F=ma …

  Is Newtonian mechanics universal? Can we use it for all types of motion?
  No.

  As objects get faster and faster, Newtonian mechanics breaks down. It makes predictions that are simply wrong.

  Eg. the momentum of an electron moving at 99% of the speed of light in a particle accelerator.

  The rate at which time passes for a GPS satellite orbiting Earth at a 4 km/s.

  Therefore, we need a new theory for objects that are moving “very fast”: Einstein’s theory of special relativity.

What do we mean by "very fast"?

- Roughly speaking, the speed of light or thereabouts.
- How fast does light travel?

  3×10^8 m/s in empty space

EXAMPLE	SPEED THAT LIGHT TRAVELS FASTER BY
A person walking	120 million times
A car driving along a highway at 60 km/h	20 million times
Boeing 747	1 million times
A beam of light orbiting the globe at the equator once each second	7 times.

Some background to special relativity

- Einstein at 16 years of age: daydream about riding alongside a beam of light

- Overturned more than 200 years of thinking about space and time.

- Important limitation:
  Only deals with constant velocities, no acceleration.

- "It followed from the special theory of relativity that mass and energy are both but different manifestations of the same thing -- a somewhat unfamiliar conception for the average mind. Furthermore, the equation E is equal to m c-squared, in which energy is put equal to mass, multiplied by the square of the velocity of light, showed that very small amounts of mass may be converted into a very large amount of energy and vice versa. The mass and energy were in fact equivalent, according to the formula mentioned above. This was demonstrated by Cockcroft and Walton in 1932, experimentally."

http://www.aip.org/history/einstein/voice1.htm

Twin starting points of special relativity

- 1. **Relativity Postulate:** The laws of physics are the same in all inertial reference frames.

- 2. **Speed of light postulate:** Light travels at the constant speed of c ($3x10^8$ ms^{-1}) through empty space relative to all inertial observers.

- *What is an inertial reference frame?*

  Take a small particle and set it in motion with a constant velocity. If it maintains this velocity, then we're in an inertial reference frame.

  Some examples:
  An astronaut in free fall hurtling towards Earth.
  A spaceship floating in outer space.

- One view of the relativity postulate:
- One morning, you wake up and find yourself in an unfamiliar room.
- A strange man and a women walk up to you and say ‘You have been kidnapped. But, we will let you go if you can tell us if the room is i) fixed to the ground and stationary with respect to it or ii) inside a plane flying at very low altitude at a constant velocity with respect to Earth.
- The relativity postulates says that there is no way to reliably distinguish between the two possibilities, no matter what equipment you have (provided you cannot get information from outside of the room. Eg. calling an outside friend).

Speed of light postulate

- Crudely speaking, 'Everyone measures light to travel at c'.
- Counter-intuitive

- What speed will you see the snowball moving towards you at?
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- What speed will you see the light moving towards you at?

  a) c

  b) c + 30 kmh^{-1}

  c) c - 30 kmh^{-1}

  d) c/(30 kmh^{-1})

What speed will you see the light moving towards you at?

a) c

b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})

What speed will you see the light moving towards you at?

a) c

b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})

What speed will you see the light moving towards you at?

a) c
b) $c + 100{,}000\ kms^{-1}$
c) $c - 100{,}000\ kms^{-1}$
d) $c/(100{,}000\ kms^{-1})$

What speed will you see the light moving towards you at?

- a) c
- b) c + 100,000 kms^{-1}
- c) c – 100,000 kms^{-1}
- d) c/(100,000 kms^{-1})

What speed will you see the light moving towards you at?

a) c

b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})

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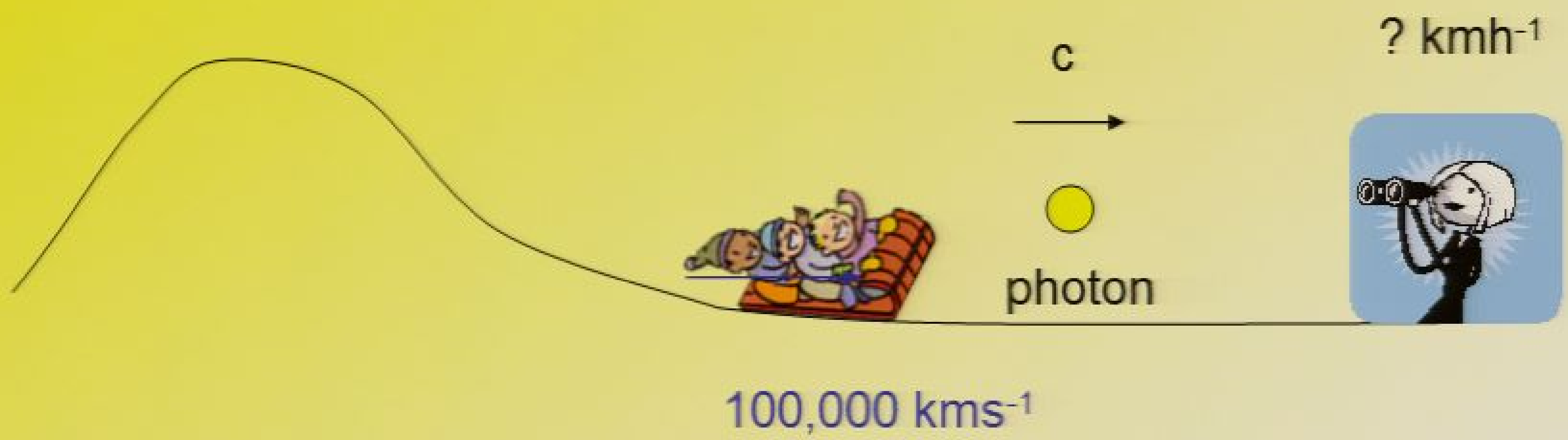
What speed will you see the light moving towards you at?

a) c

b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})



What speed will you see the light moving towards you at?

a) c

b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})

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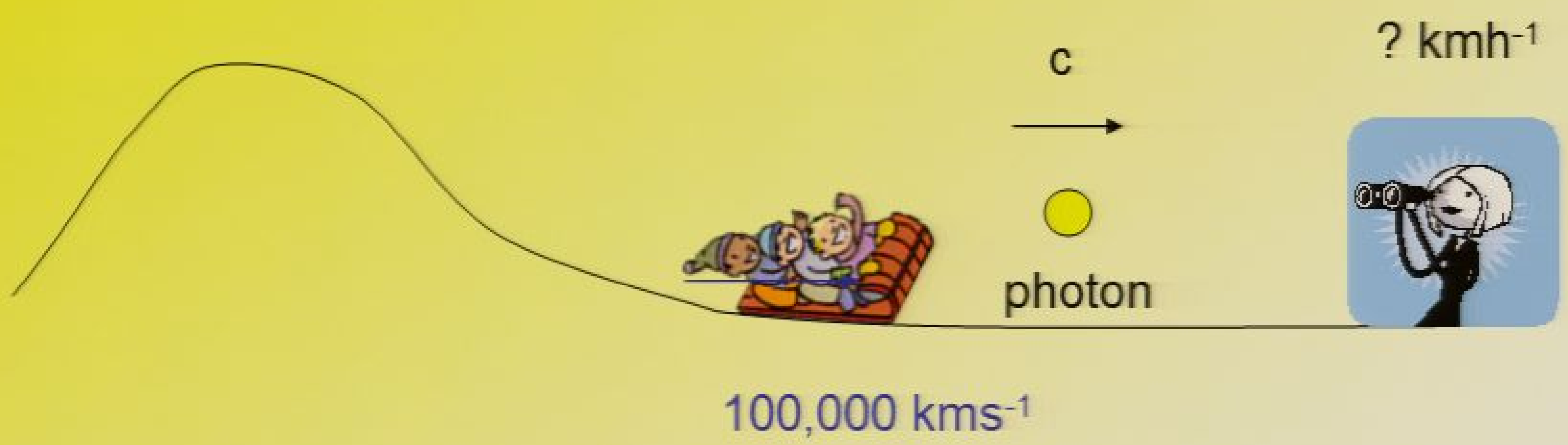
b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})



What speed will you see the light moving towards you at?

a) c
b) c + 100,000 kms^{-1}
c) c – 100,000 kms^{-1}
d) c/(100,000 kms^{-1})

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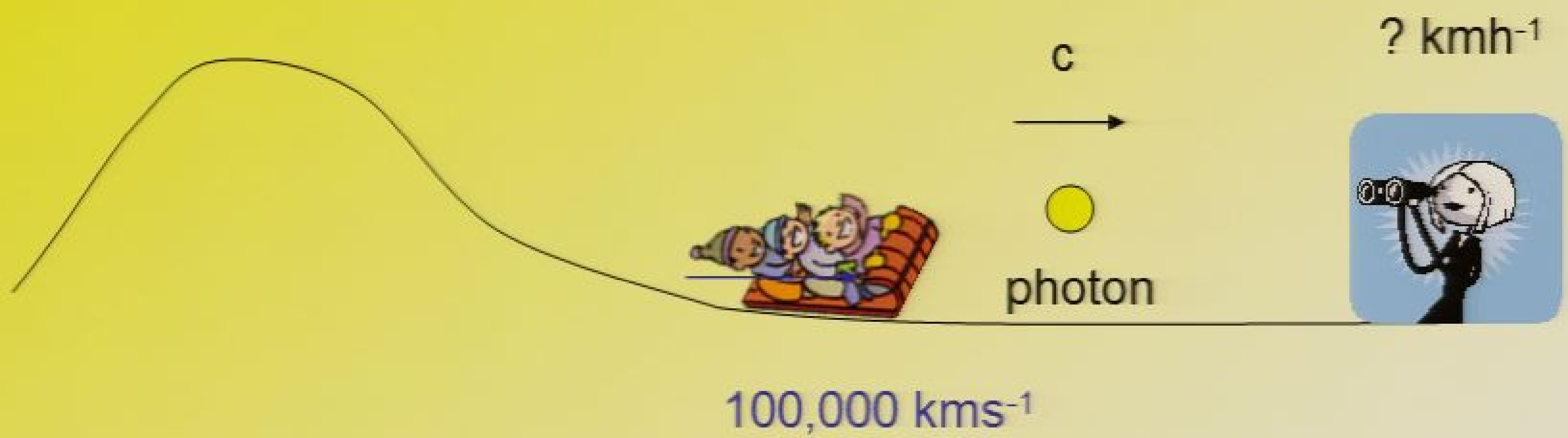
c) c – 100,000 kms^{-1}
d) c/(100,000 kms^{-1})



What speed will you see the light moving towards you at?

a) c

b) c + 100,000 kms^{-1}

c) c – 100,000 kms^{-1}

d) c/(100,000 kms^{-1})

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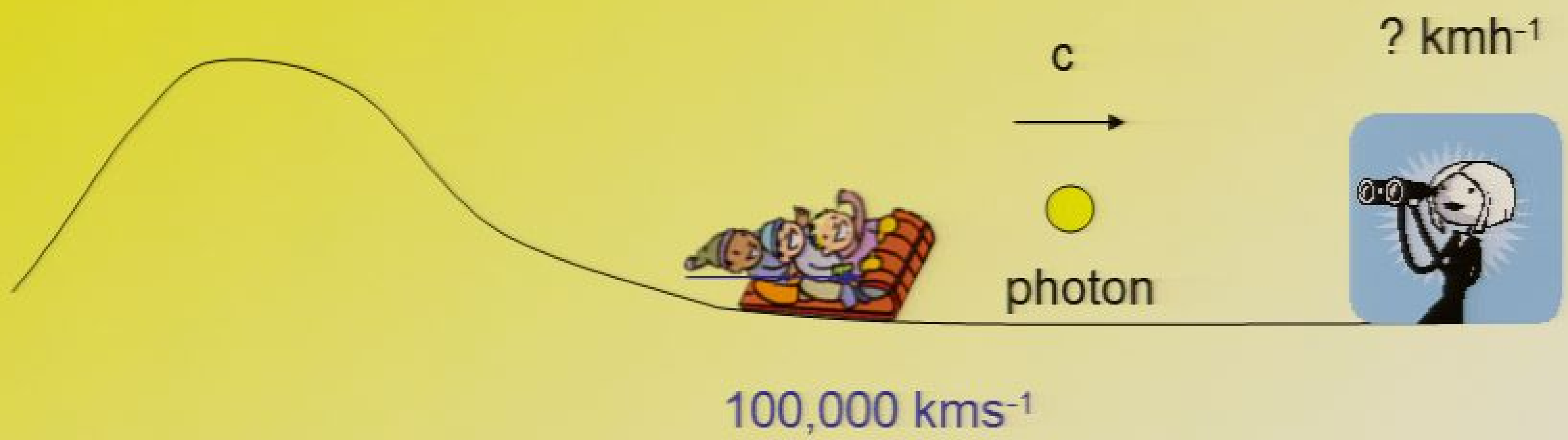
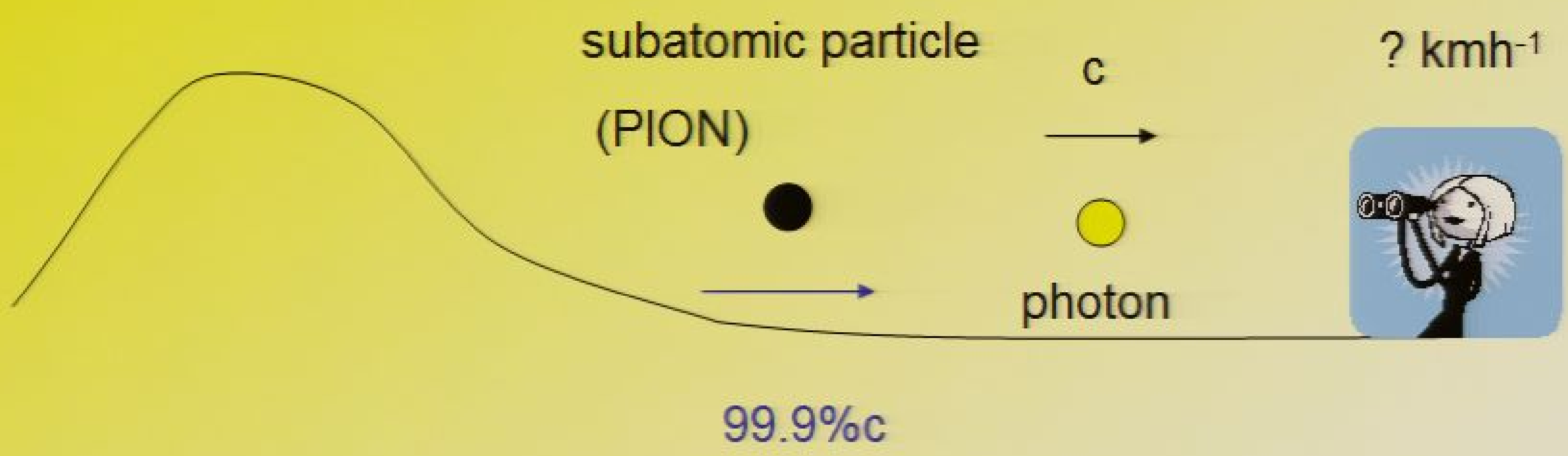


What speed will you see the light moving towards you at?

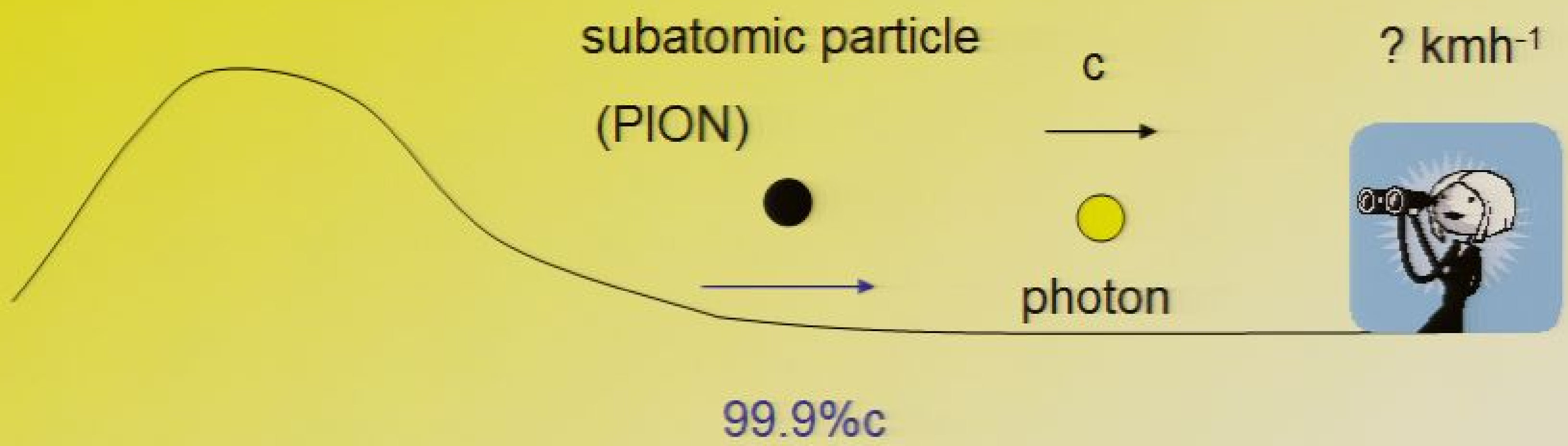
a) c
b) c + 100,000 kms^{-1}
c) c – 100,000 kms^{-1}
d) c/(100,000 kms^{-1})



- What speed will you see the light moving towards you at?
- a) c
- b) 199.9% c
- c) 99.9% c
- d) 50% c

CERN, 1964

"Test of the second postulate of special relativity in the GeV region", T Alvaeger, FJM Farley, J Kjellman and I Wallin October 1, **1964**, Physics Letters **12** 3 pp. 260-262



- What speed will the people on the sled see the light moving away from them at?

  a) c

  b) 199.9% c

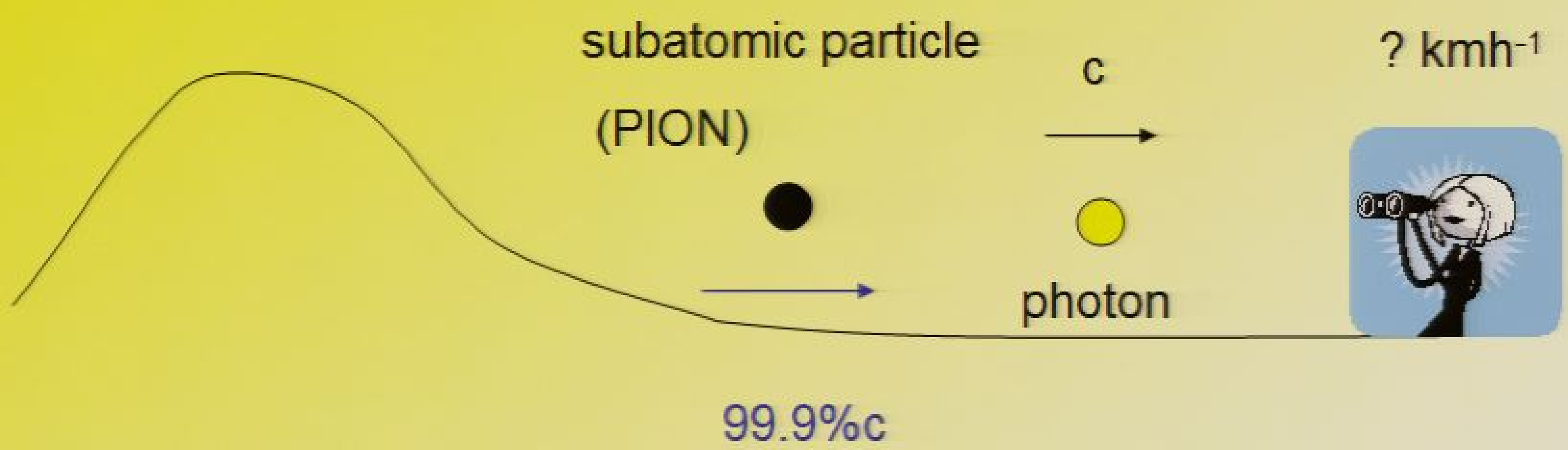
  c) 99.9% c

  d) 0.1% c

CERN, 1964

"Test of the second postulate of special relativity in the GeV region", T Alvaeger, FJM Farley, J Kjellman and I Wallin October 1, **1964**, Physics Letters **12** 3 pp. 260-262

End of slide show, click to exit.



- What speed will the people on the sled see the light moving away from them at?

  a) c

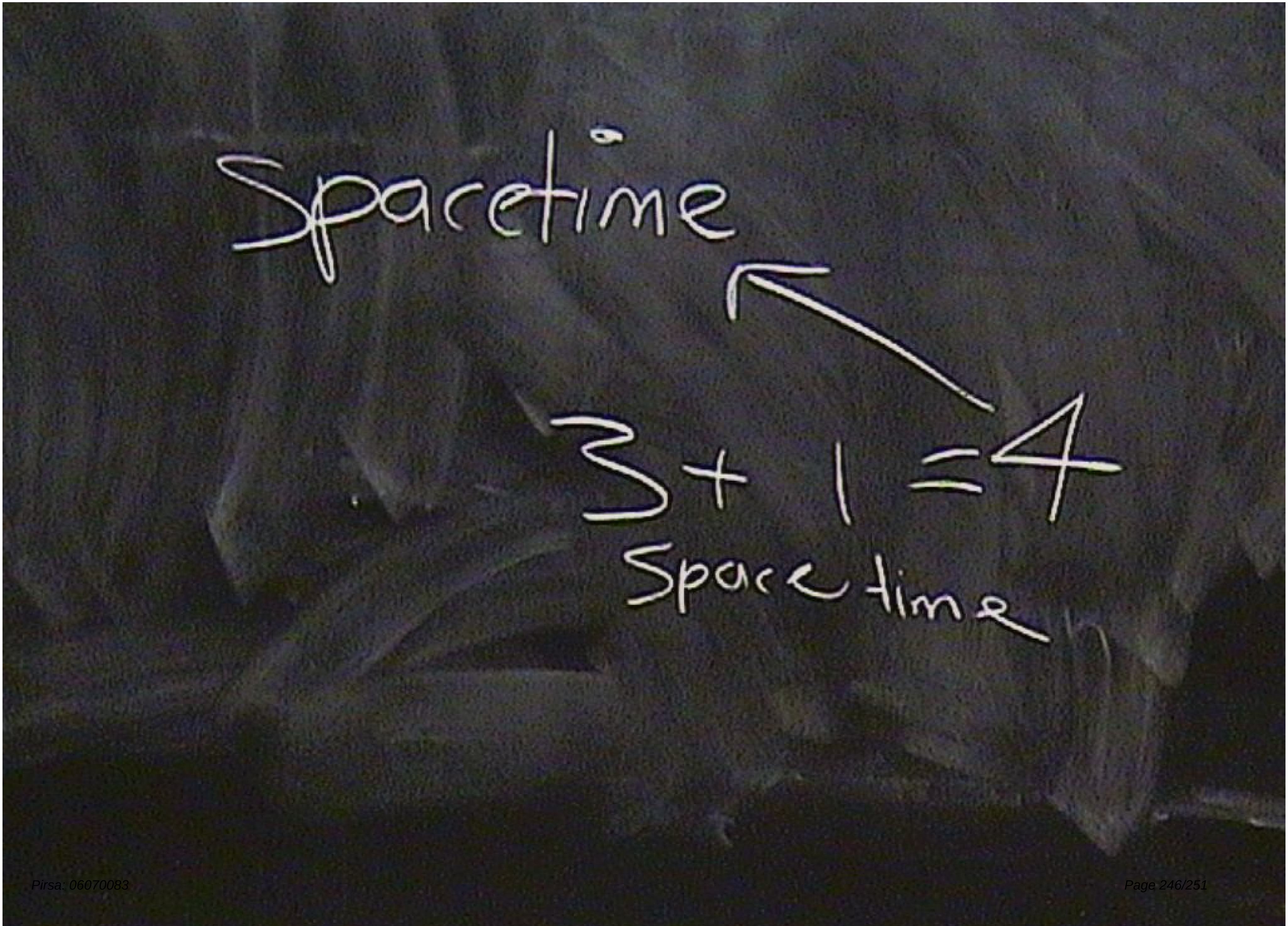
  b) 199.9% c

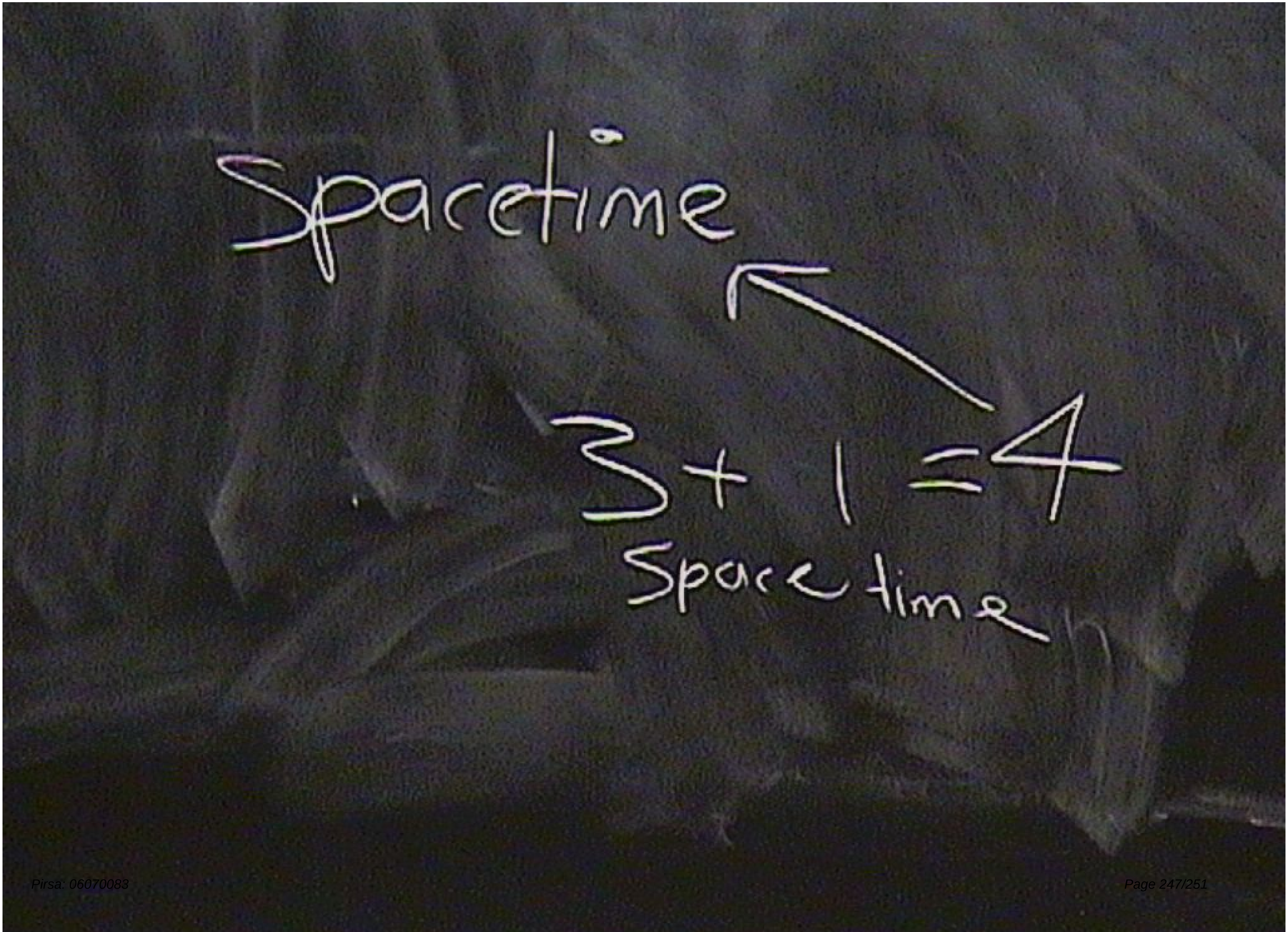
  c) 99.9% c

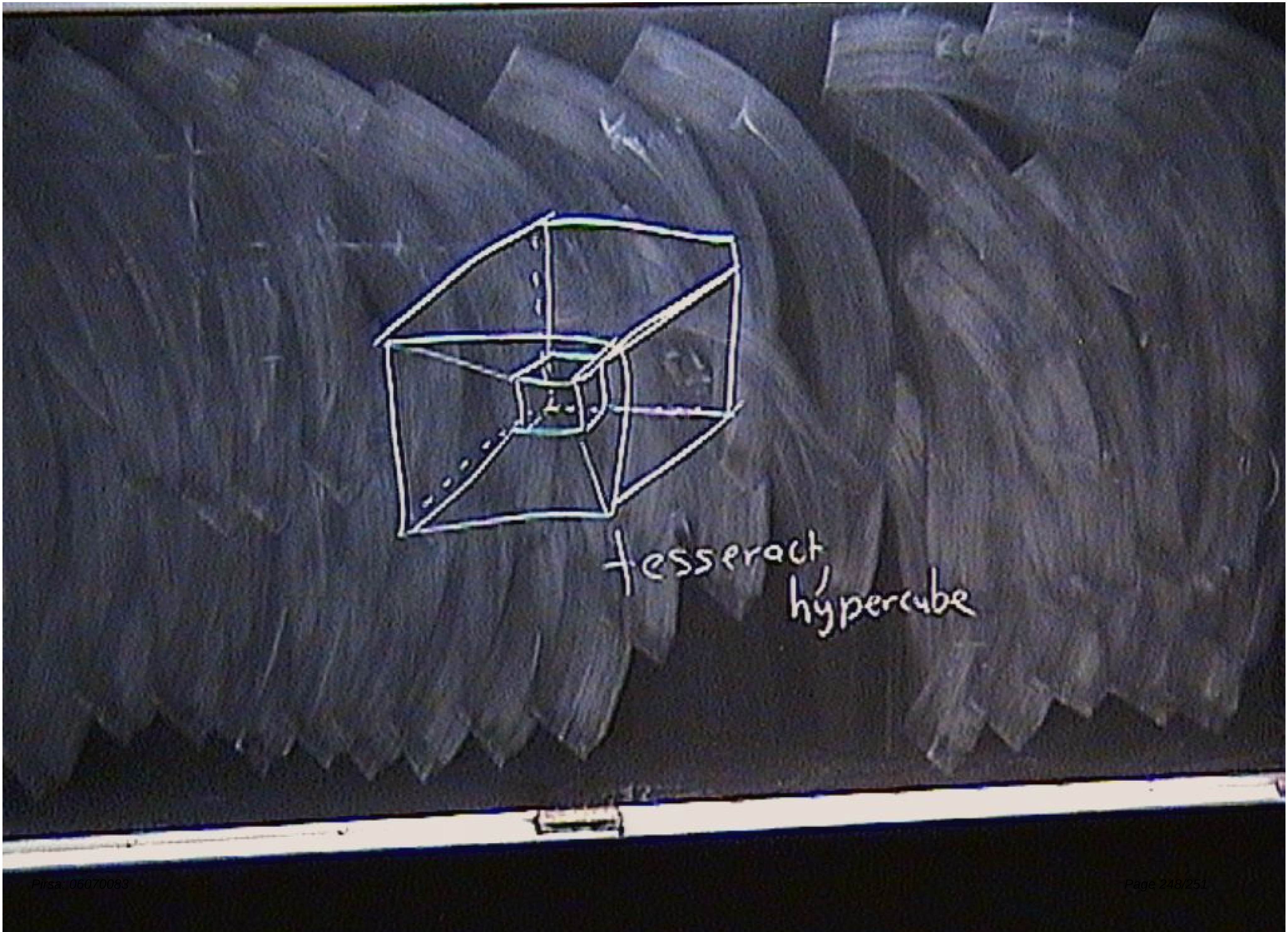
  d) 0.1% c

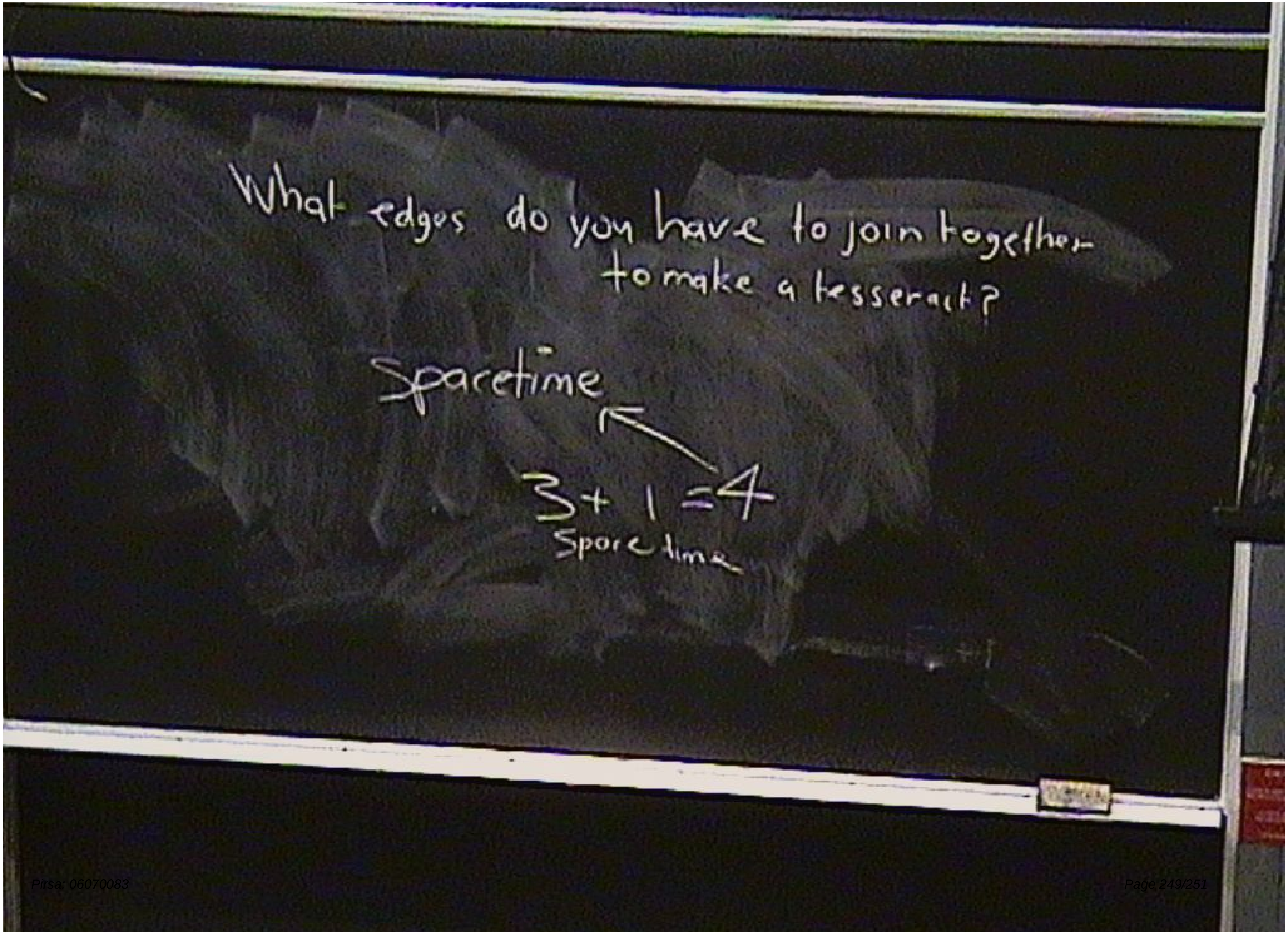
CERN, 1964

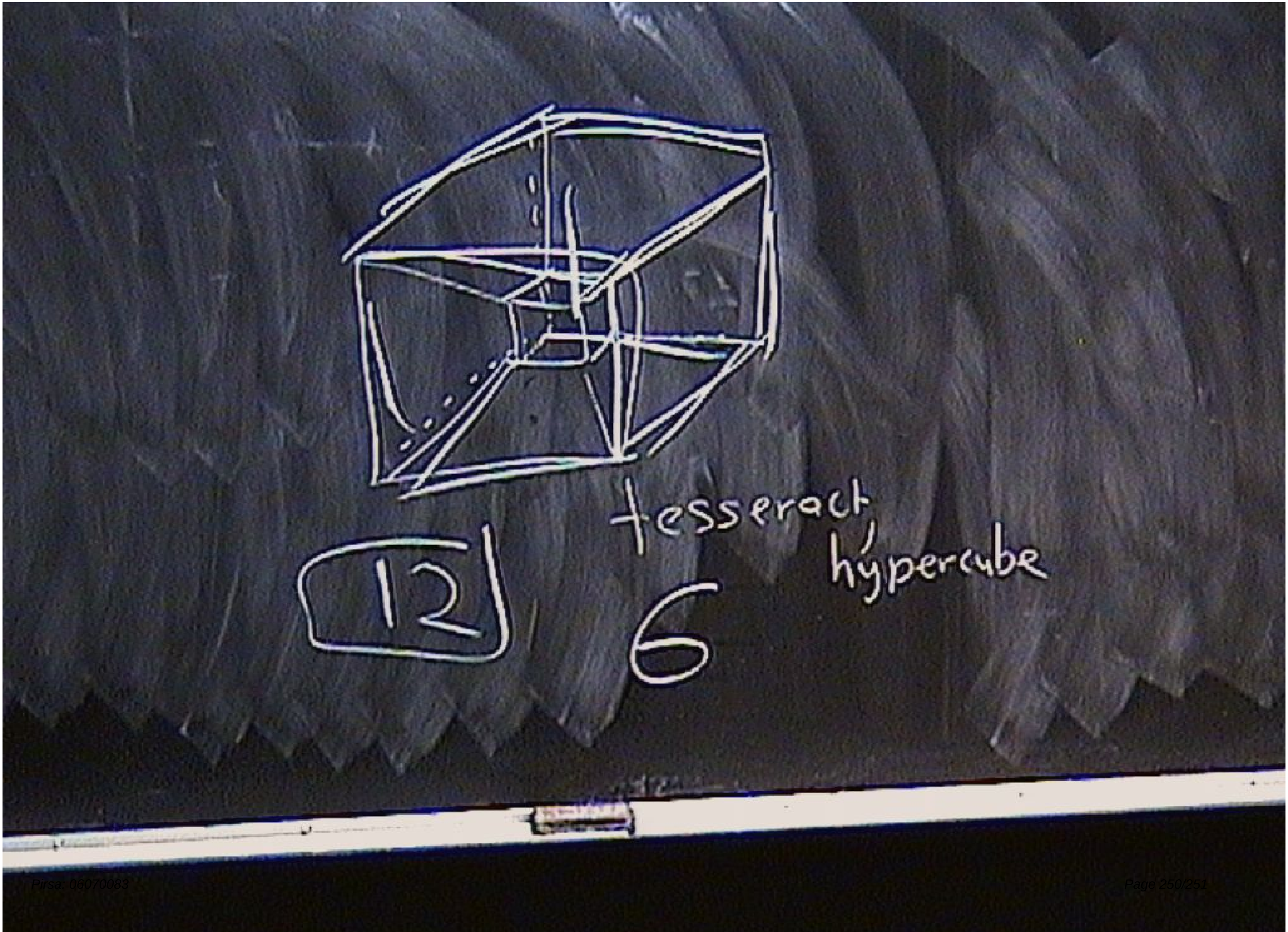
"Test of the second postulate of special relativity in the GeV region", T Alvaeger, FJM Farley, J Kjellman and I Wallin October 1, **1964**, Physics Letters **12** 3 pp. 260-262

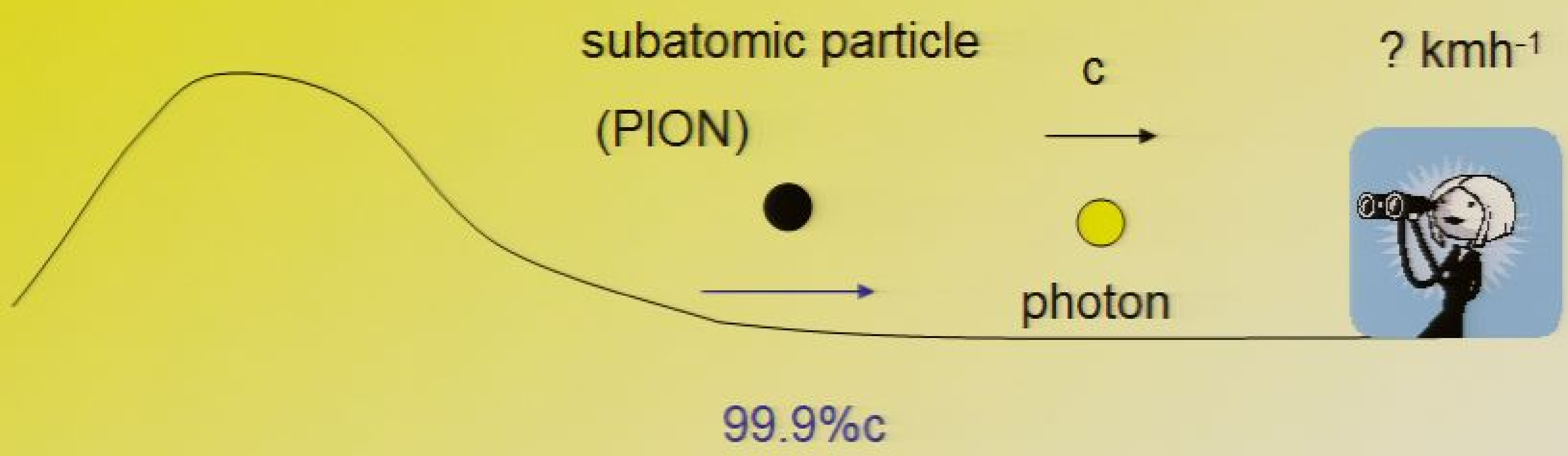

Spacetime
3+1=4
Space time


Spacetime
3+1=4
Space time


tesseract
hypercube


What edges do you have to join together
to make a tesseract?
Spacetime
3+1=4
Space time


tesseract
hypercube
12
6



- What speed will the people on the sled see the light moving away from them at?

  a) c

  b) 199.9% c

  c) 99.9% c

  d) 0.1% c

CERN, 1964

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