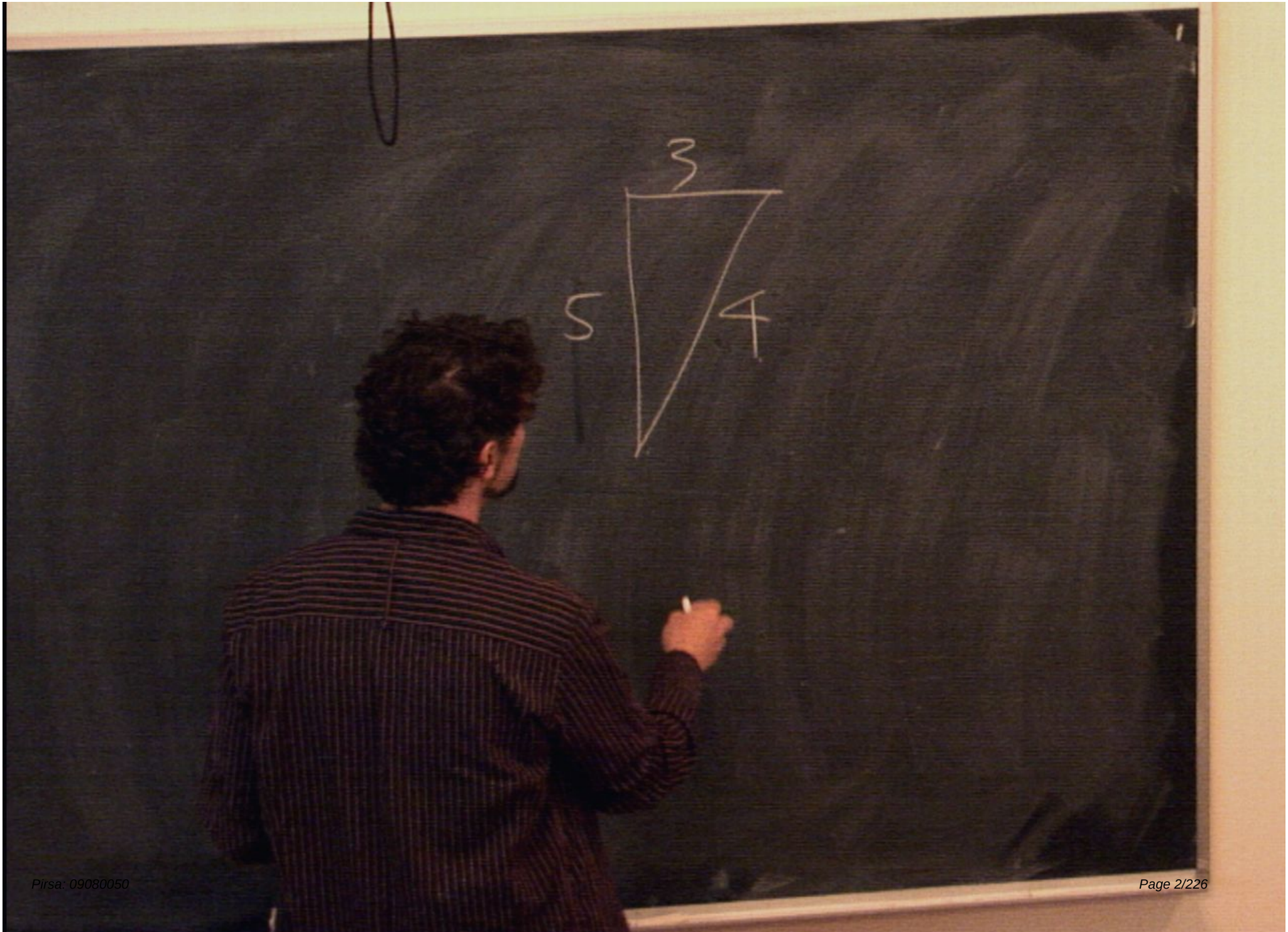
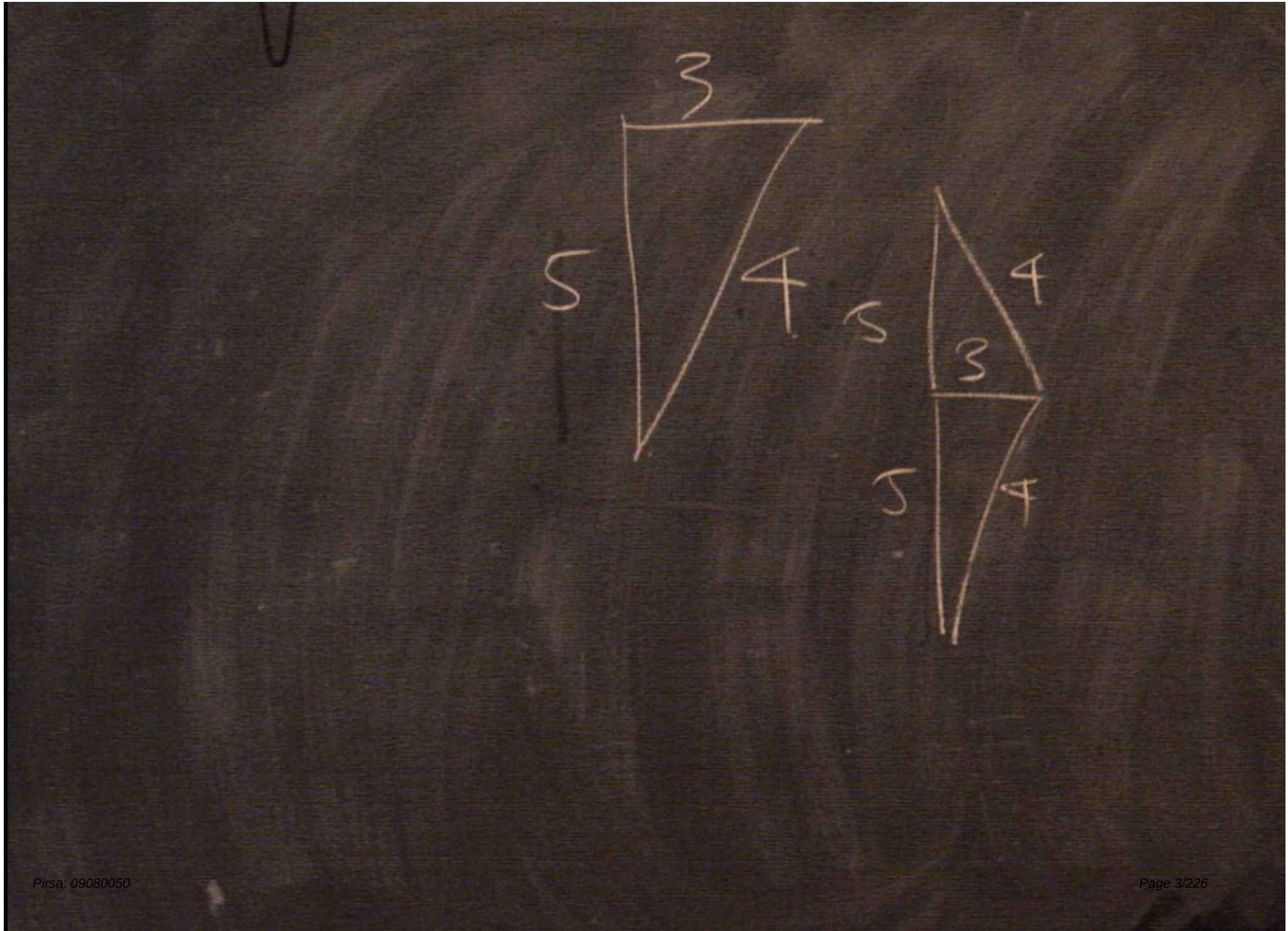
Title: Relativity 3

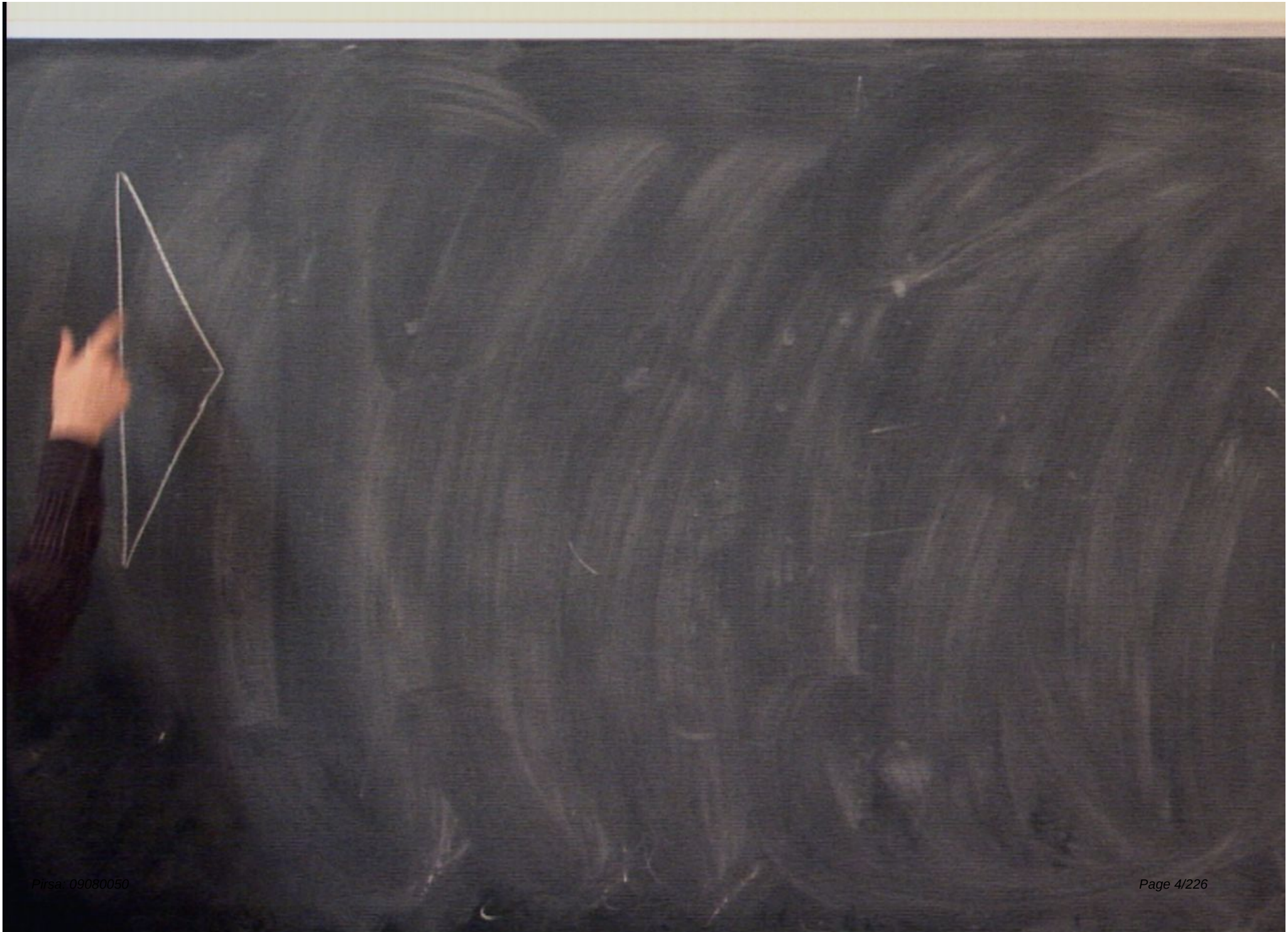
Date: Aug 12, 2009 03:00 PM

URL: http://pirsa.org/09080050

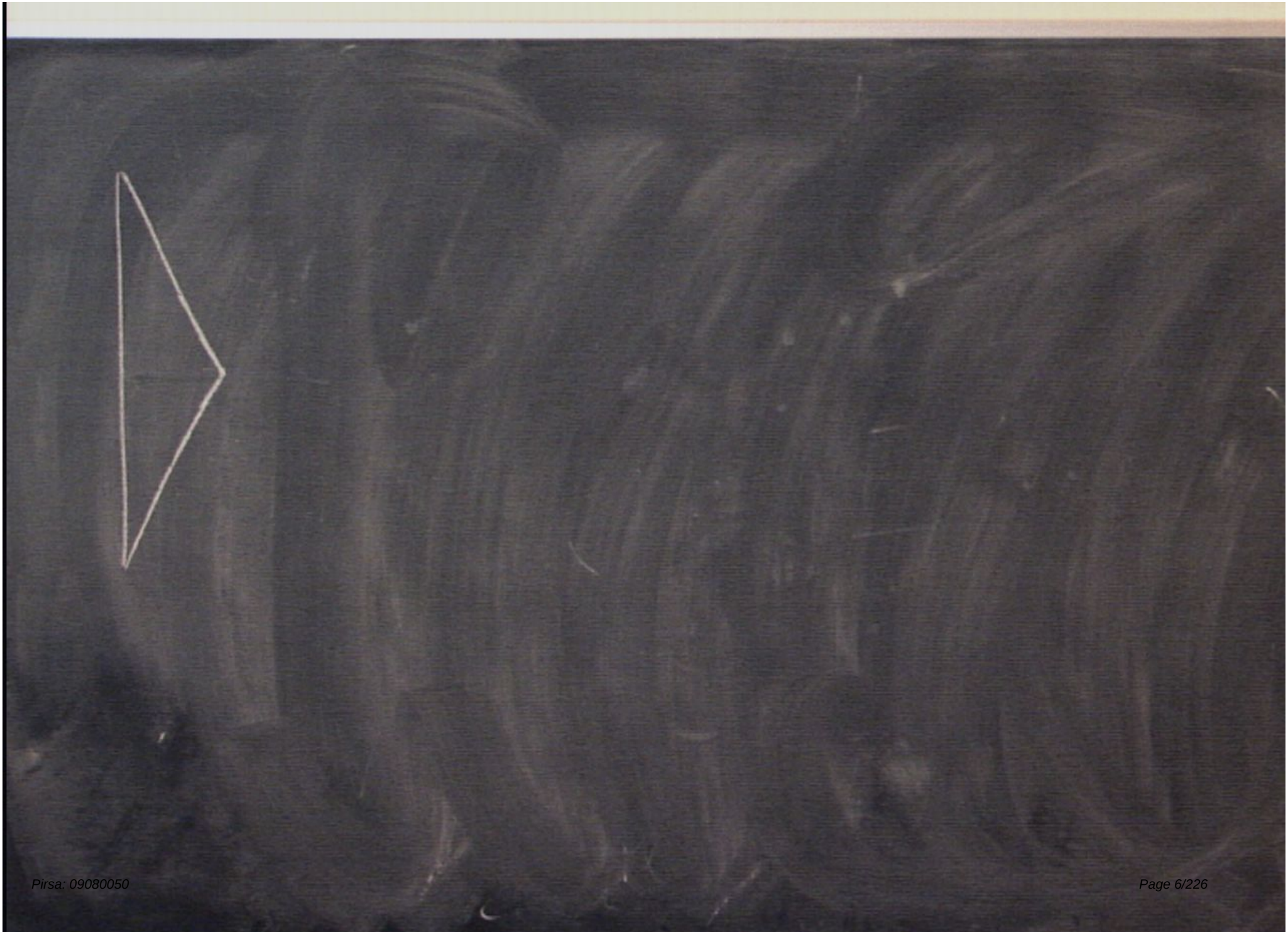
Abstract: Clock synchronization, relativity of simultaneity, nature of space, and how a universal speed limit can make sense.

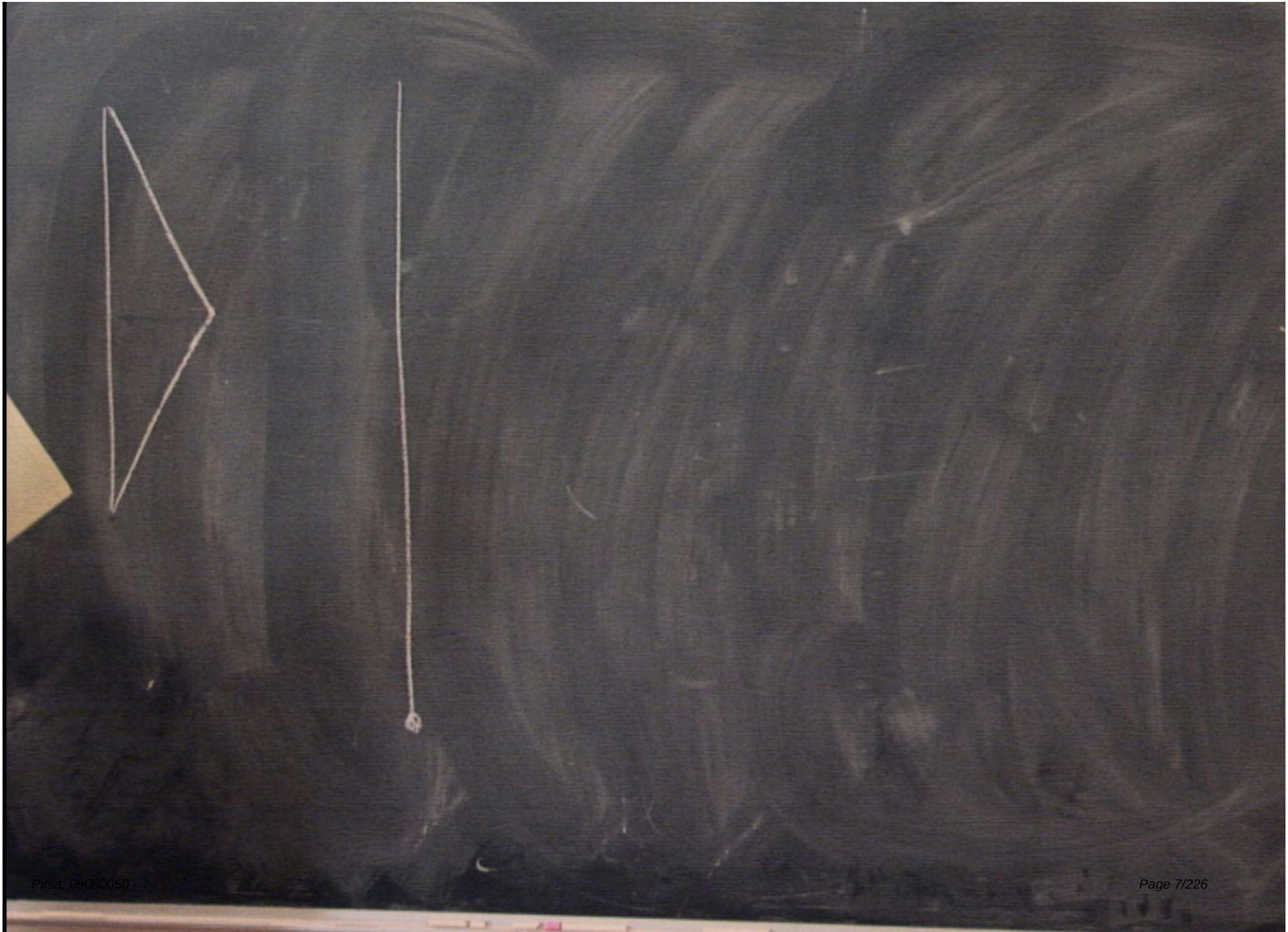

3
5
4


3
5
4
5
4
3
5
4

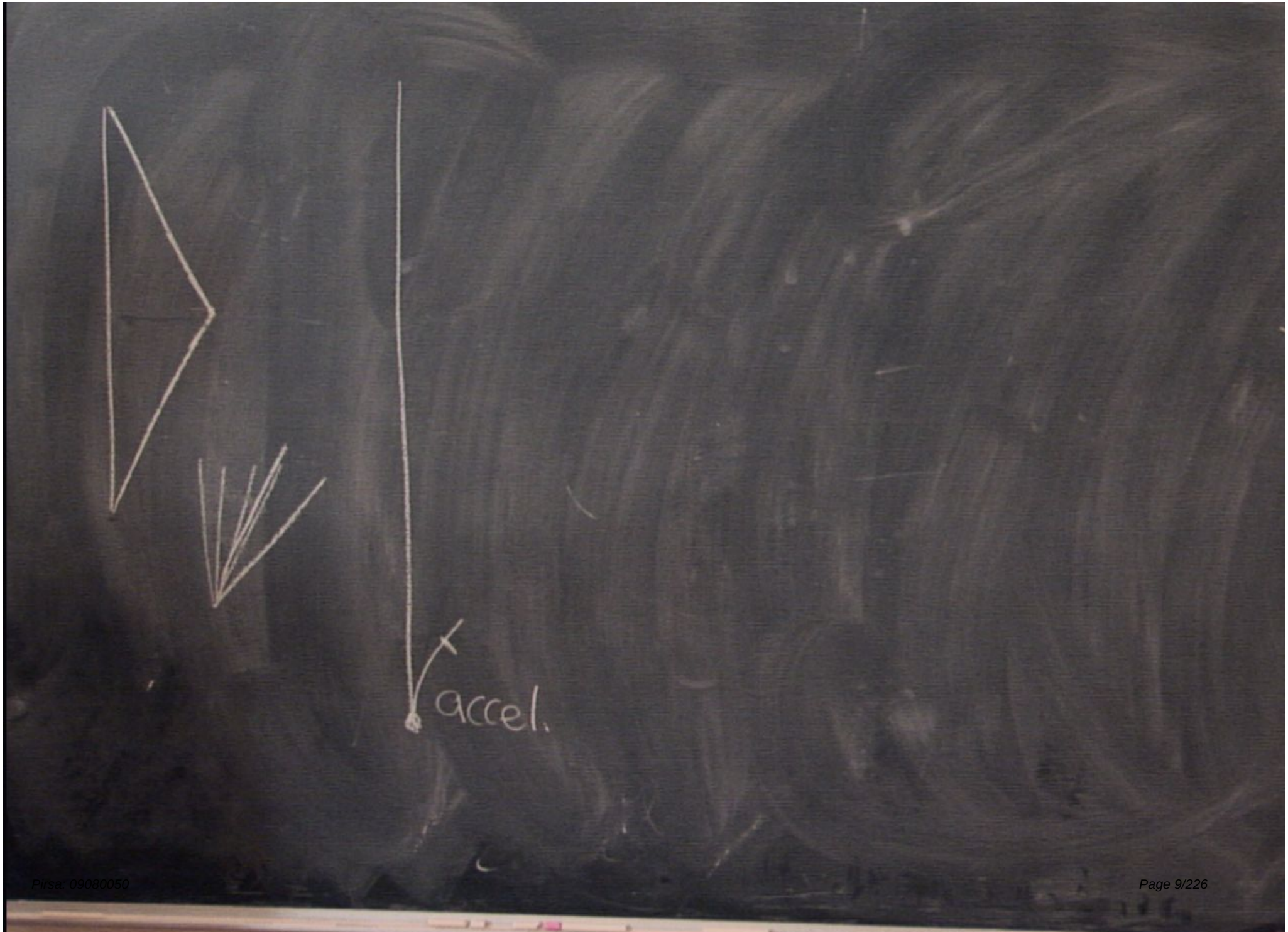


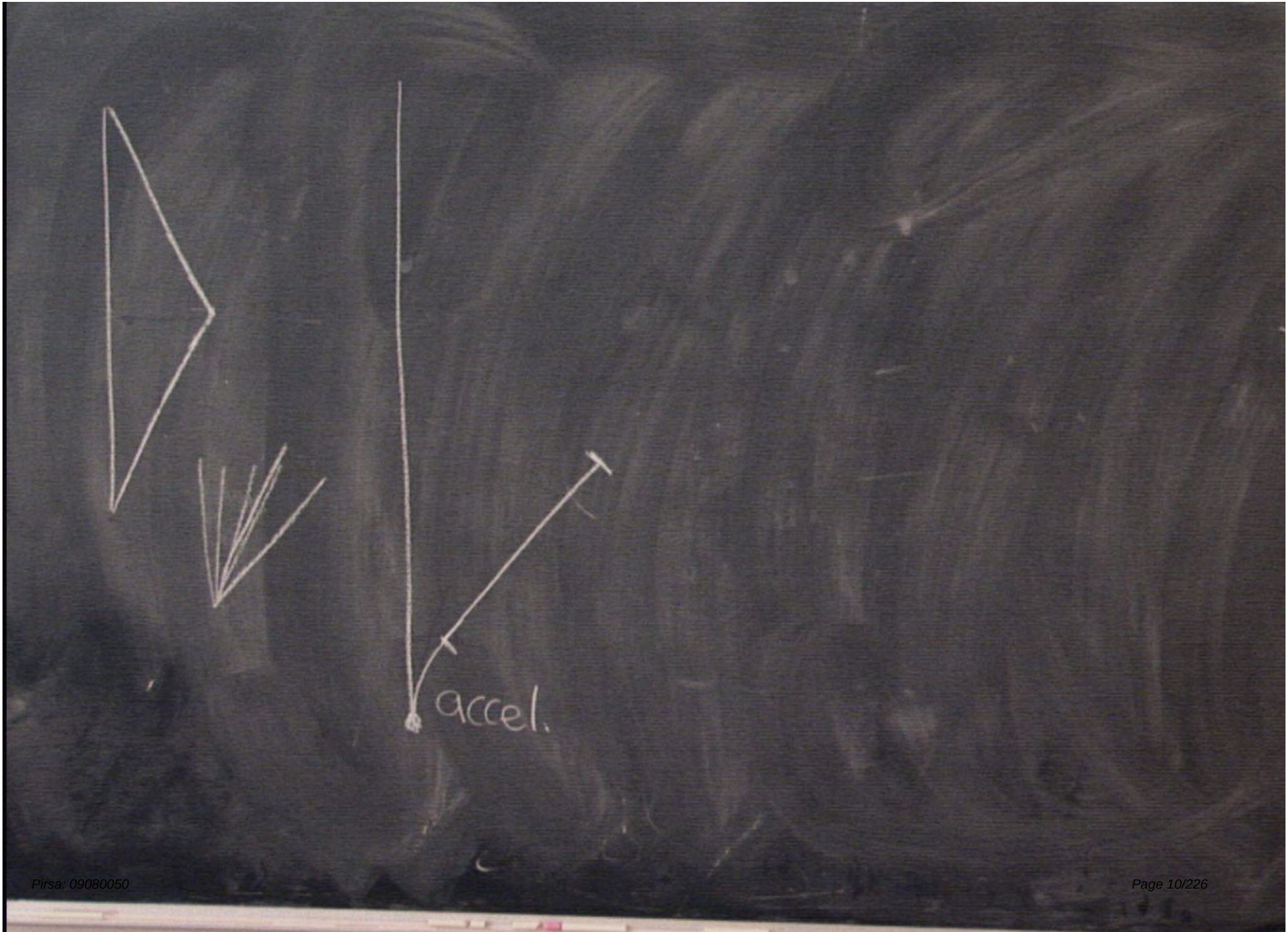


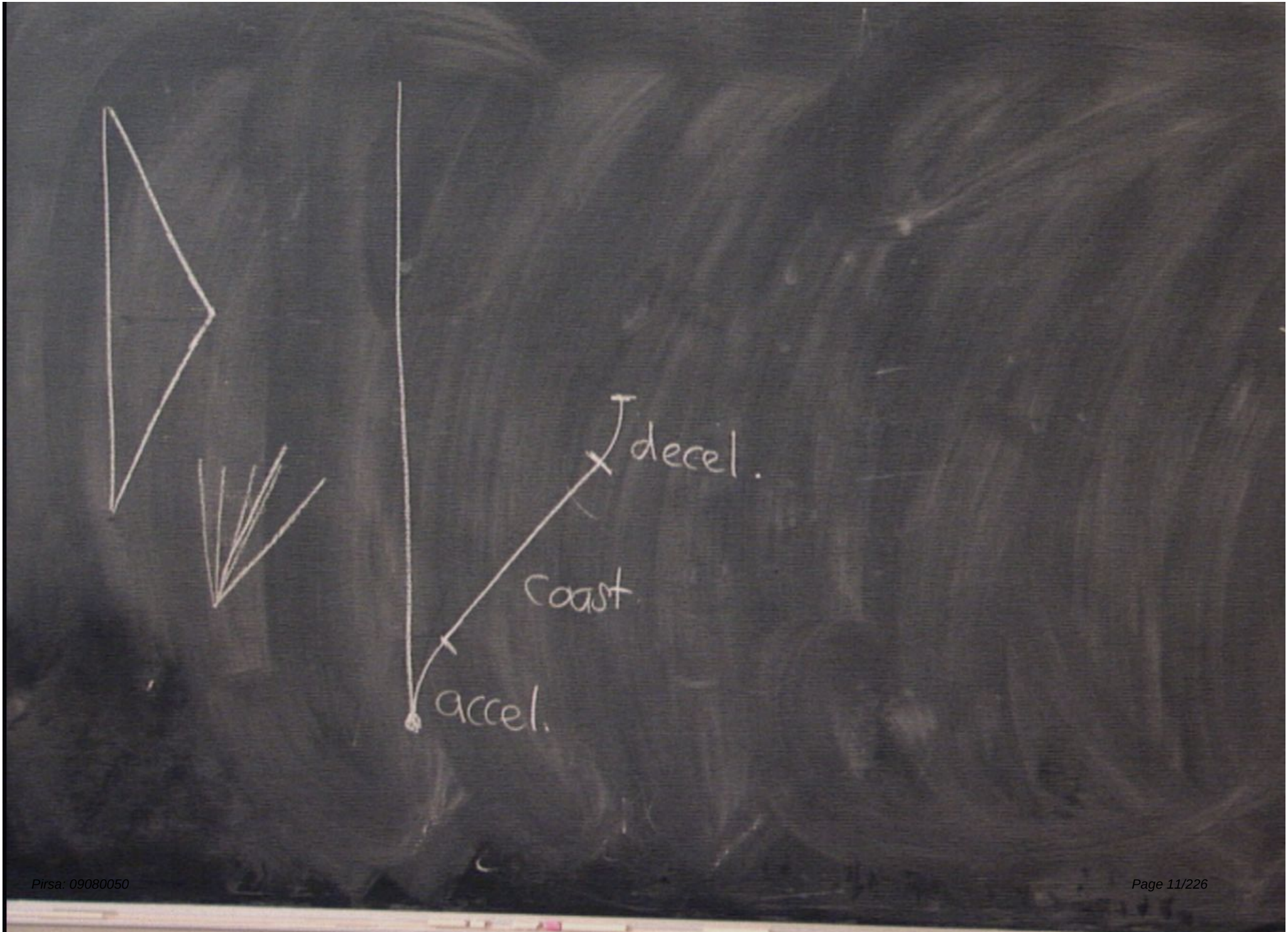


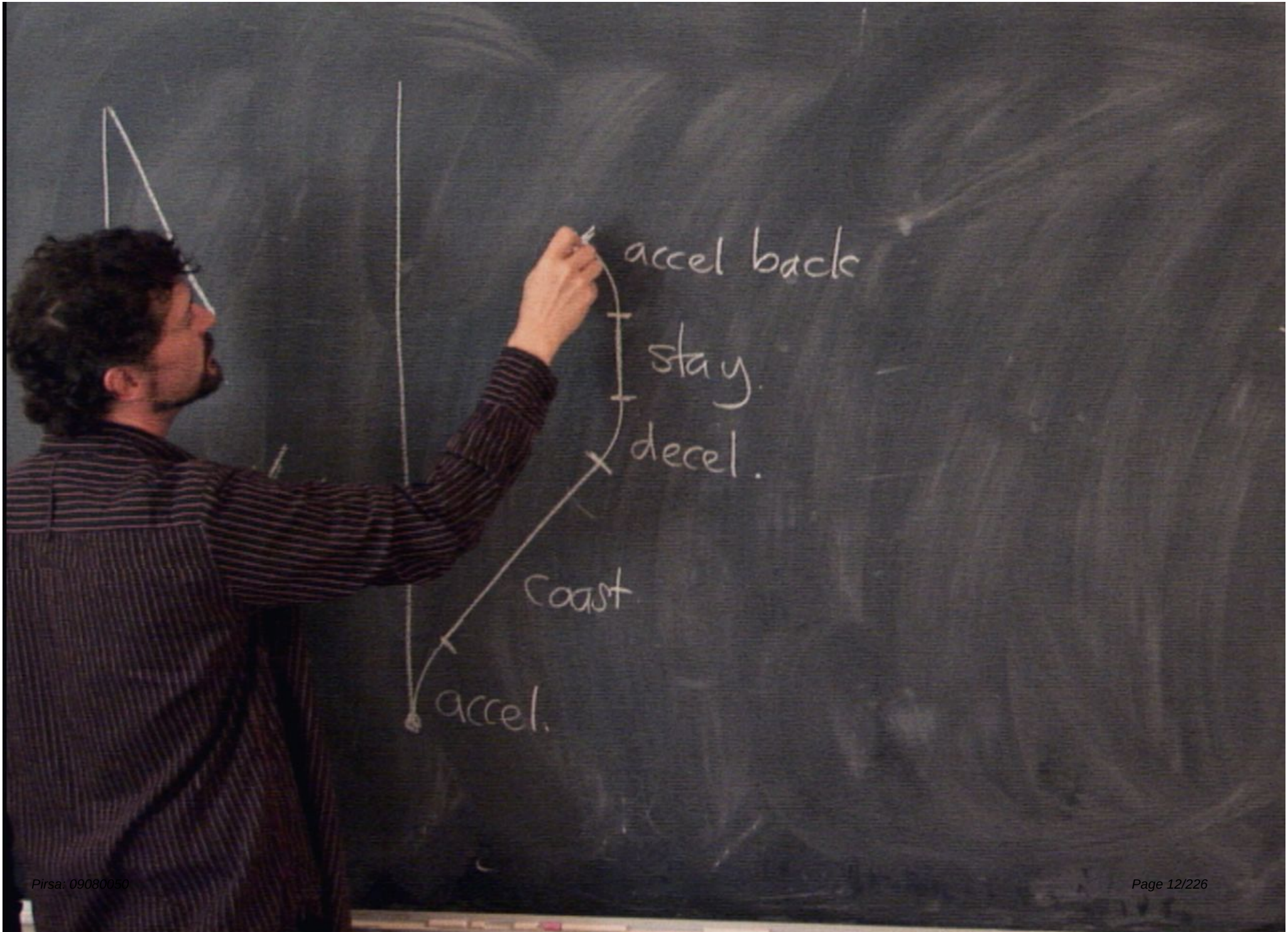


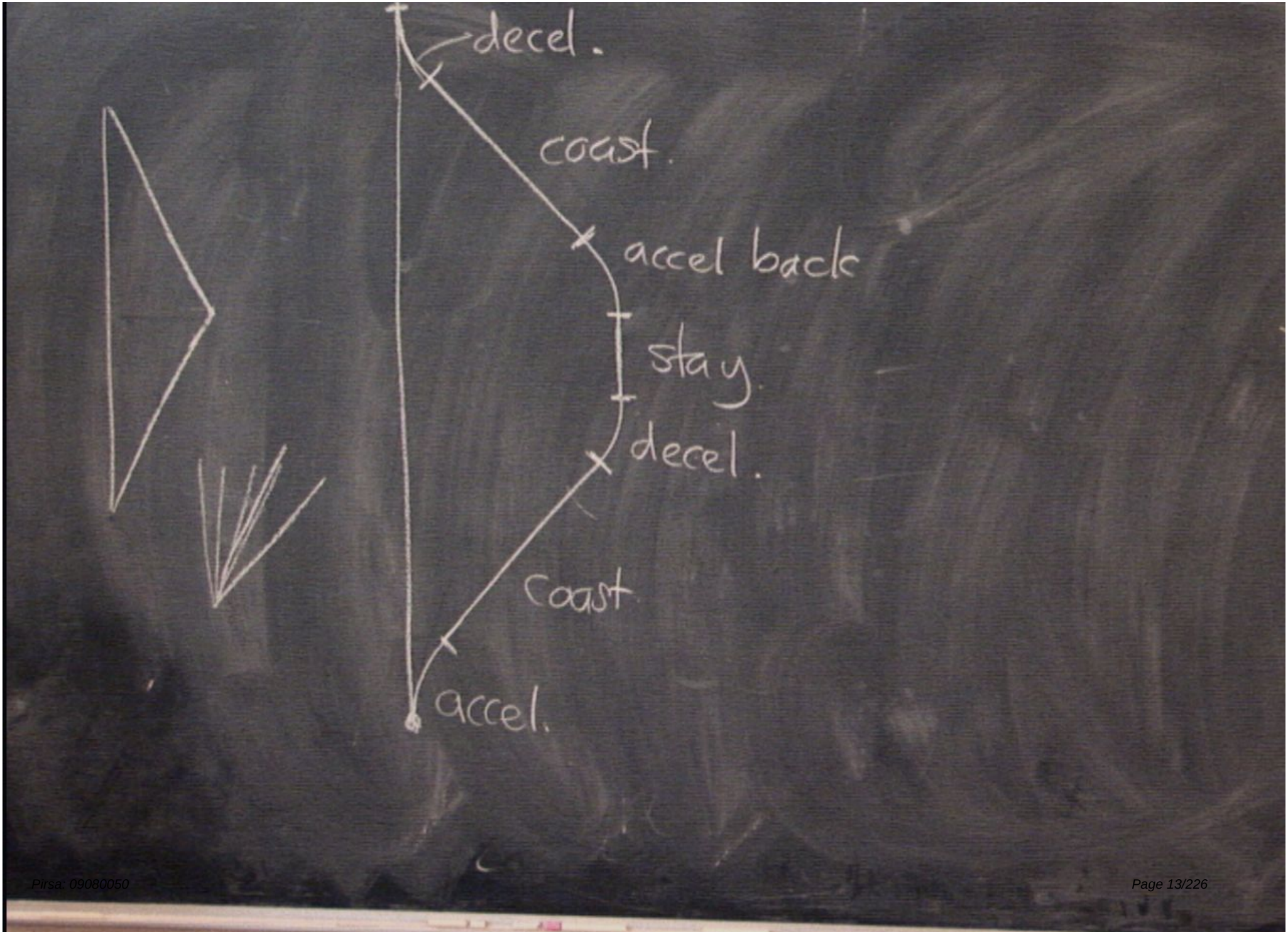


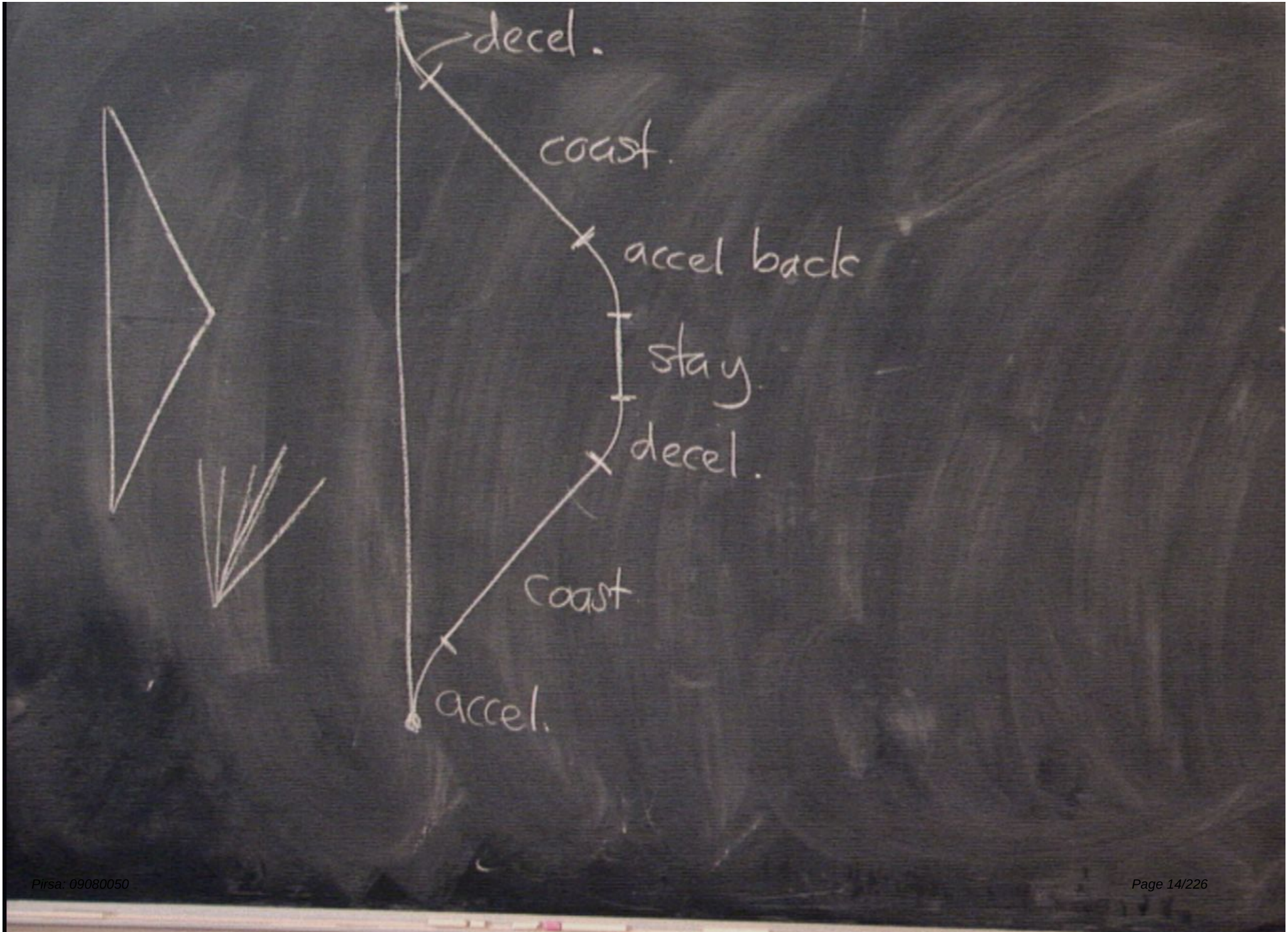

accel.

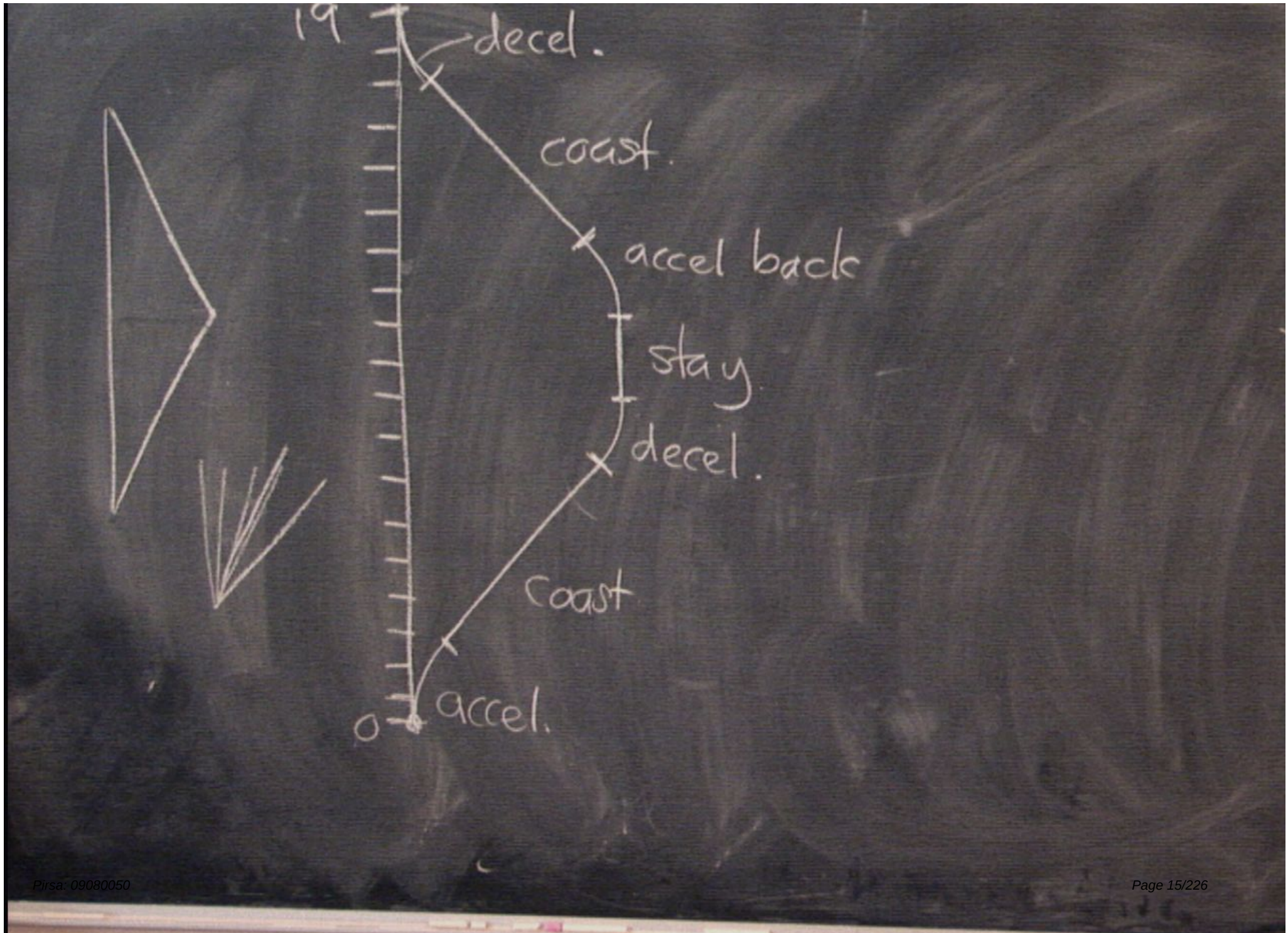

accel.

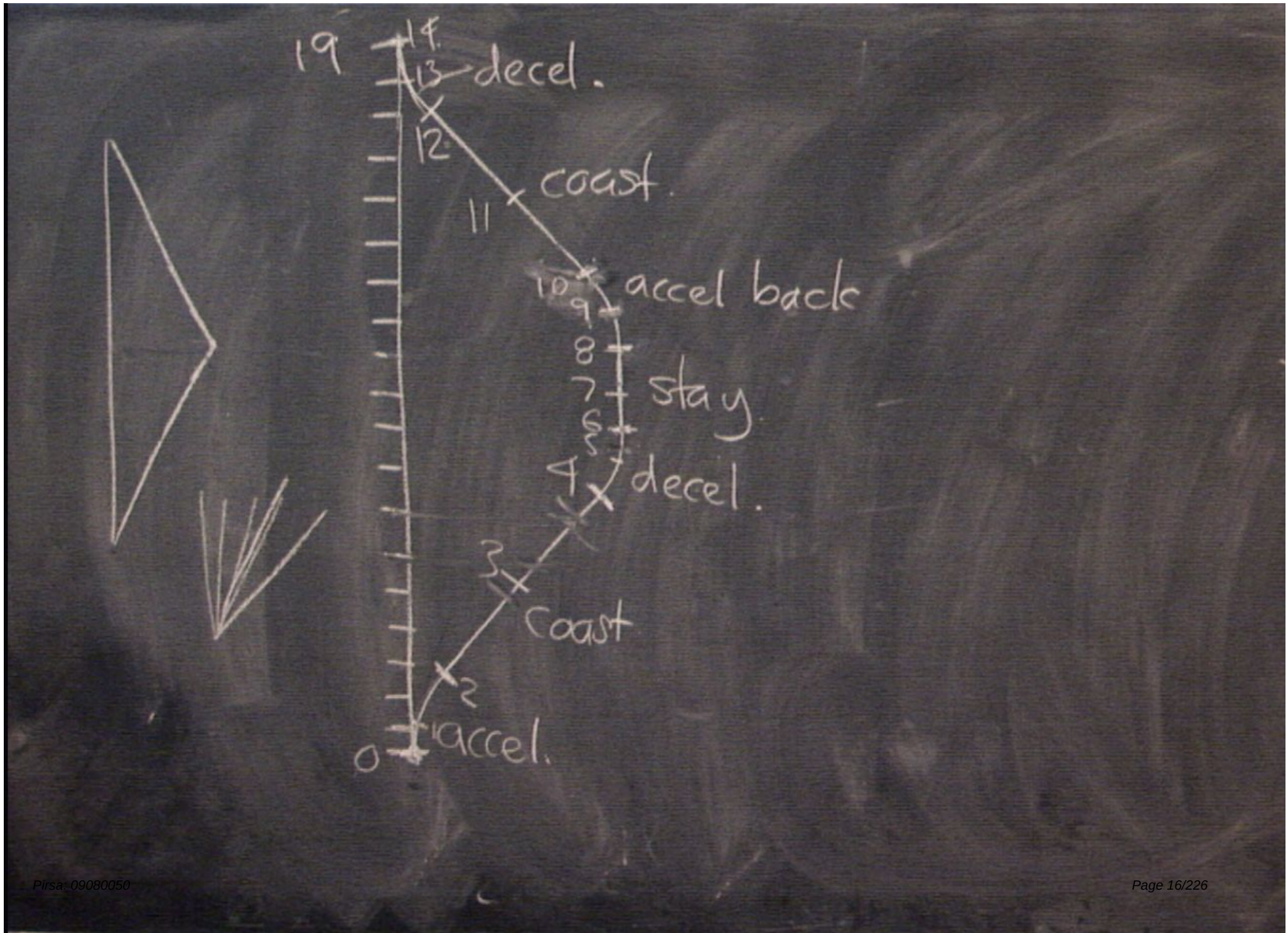

decel.
coast
accel.

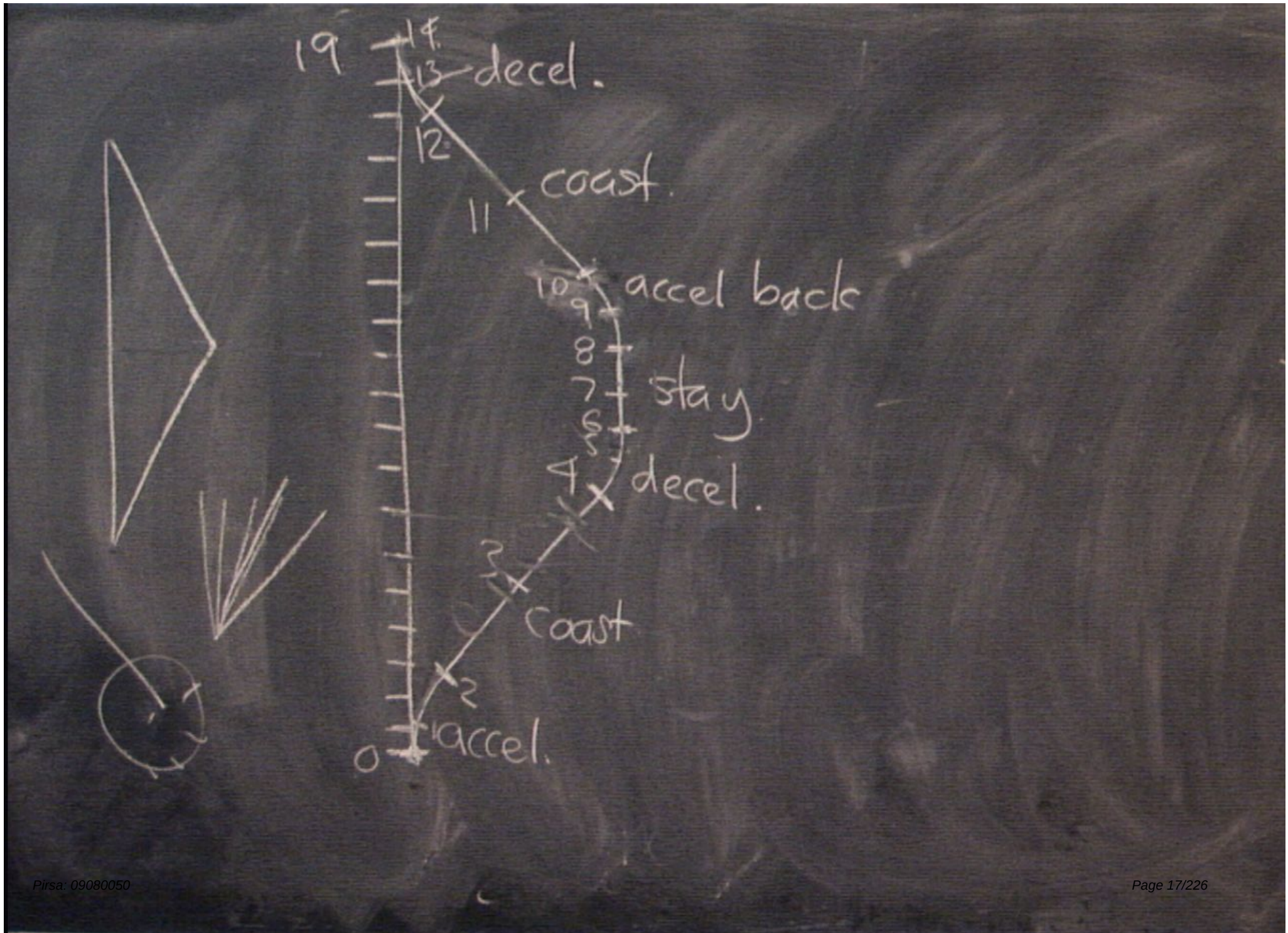

accel back
stay.
decel.
coast
accel.

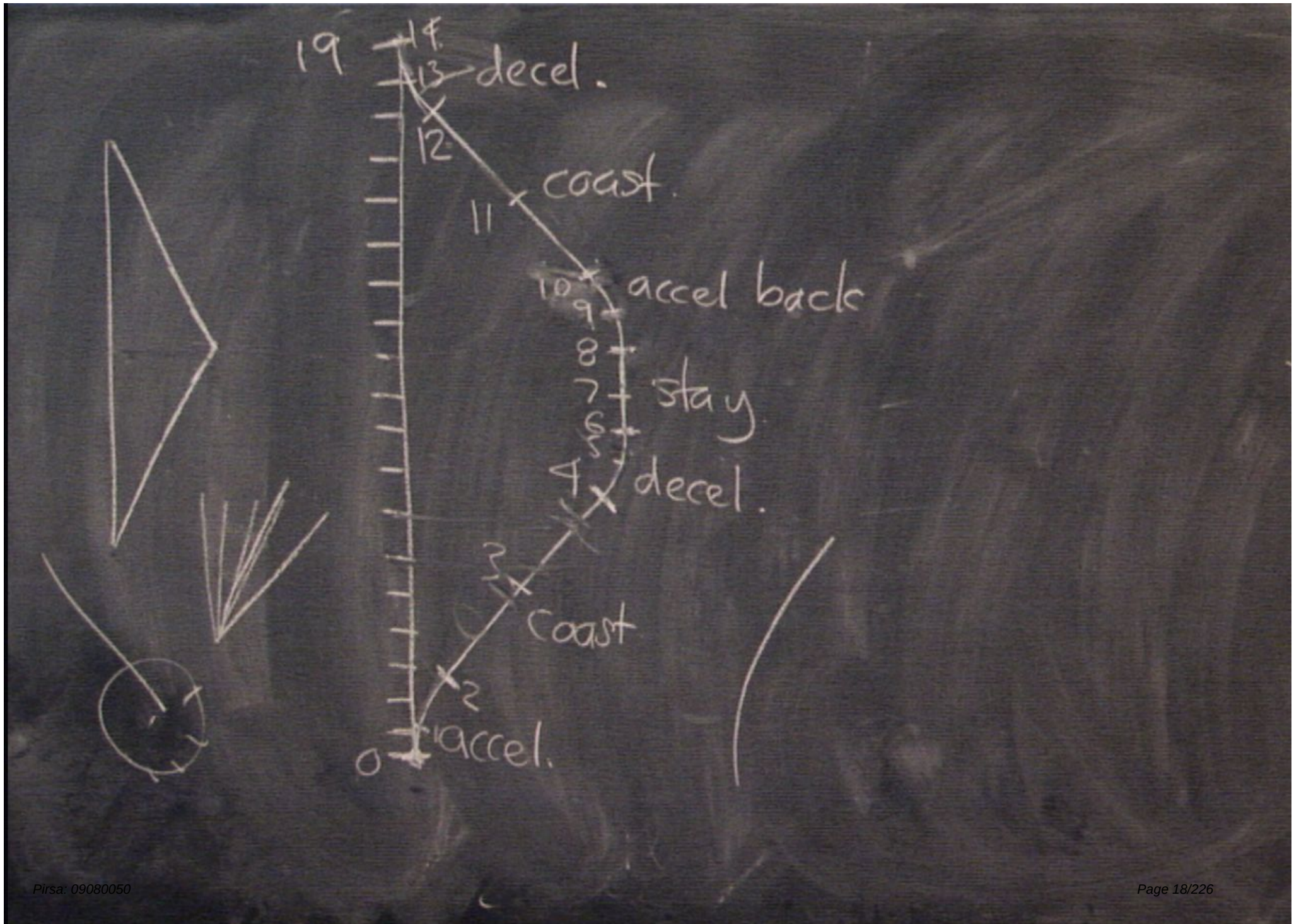

decel.
coast.
accel back
stay.
decel.
coast
accel.

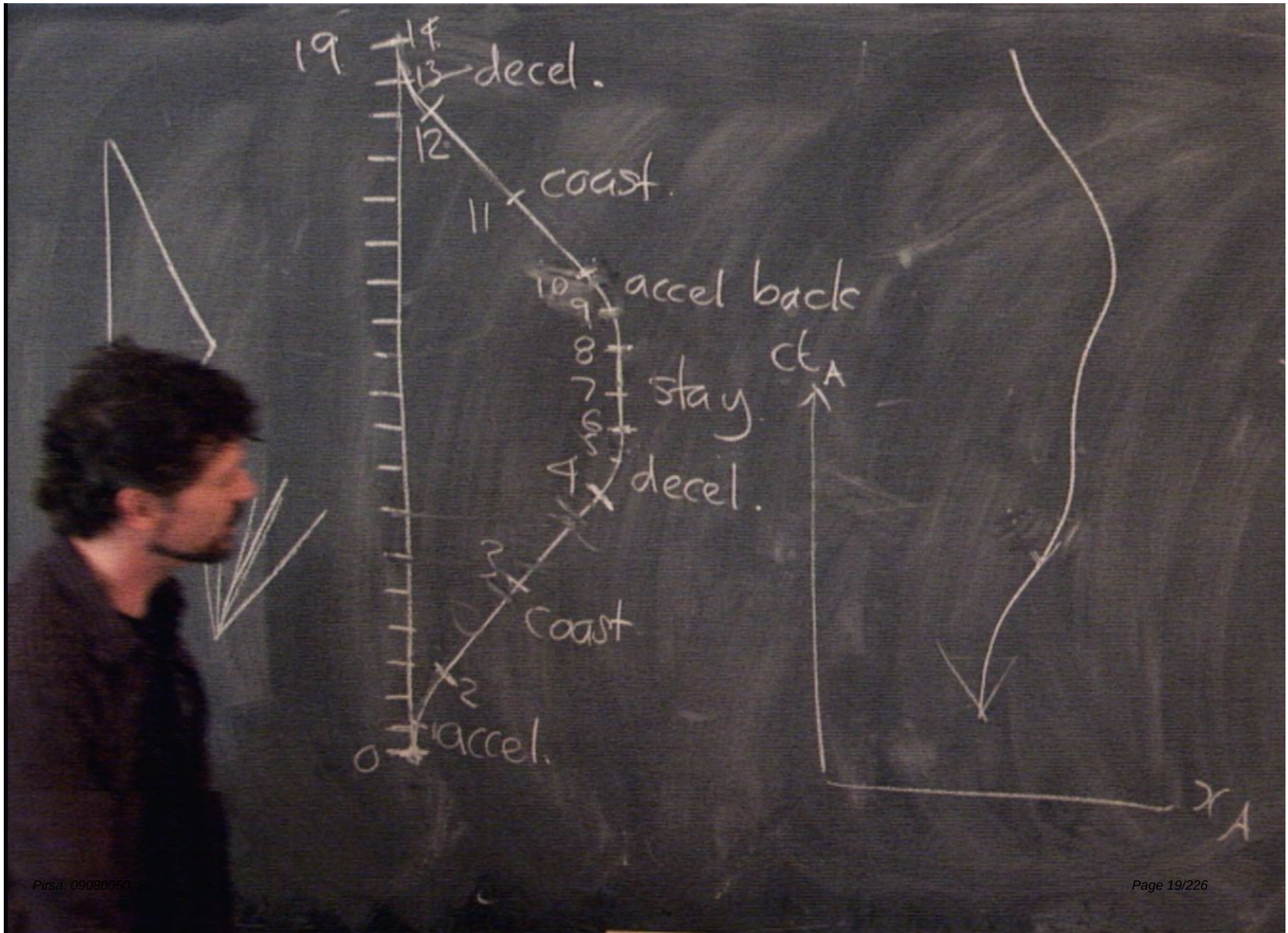

decel.
coast.
accel back
stay.
decel.
coast
accel.

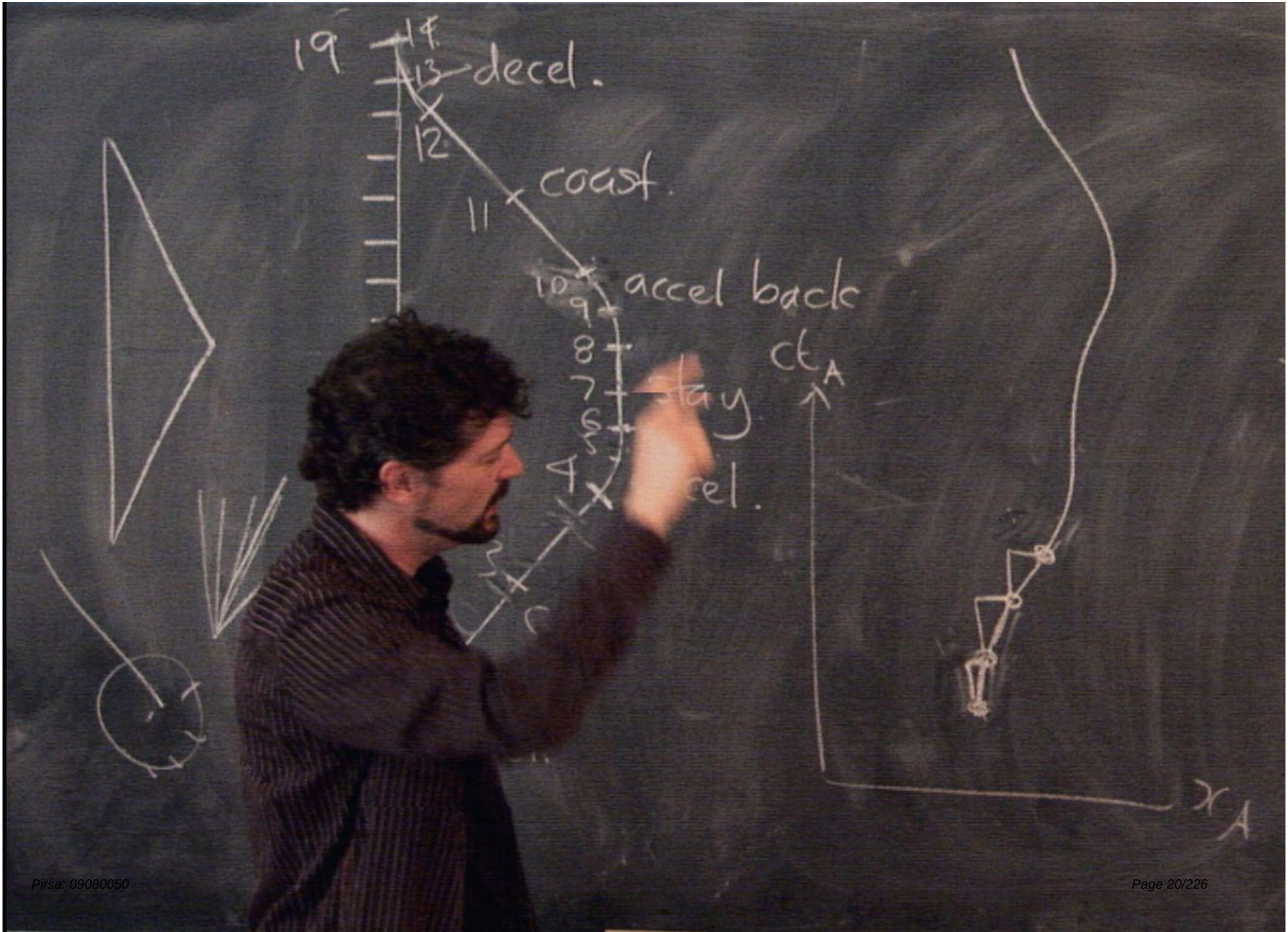

19
decel.
coast.
accel back
stay
decel.
coast
0
accel.

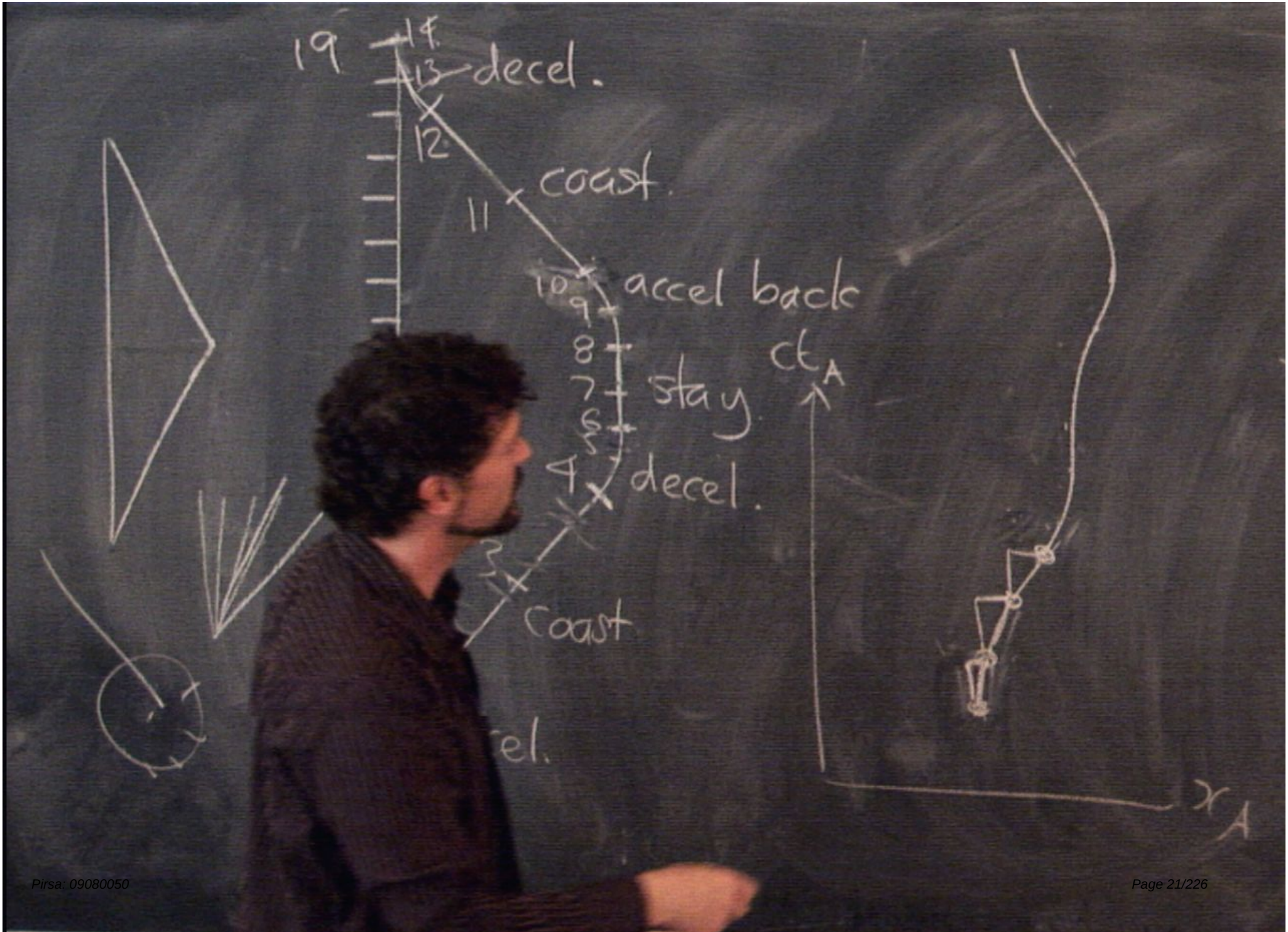

19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
stay
6
5
4
decel.
3
coast
2
accel.
0

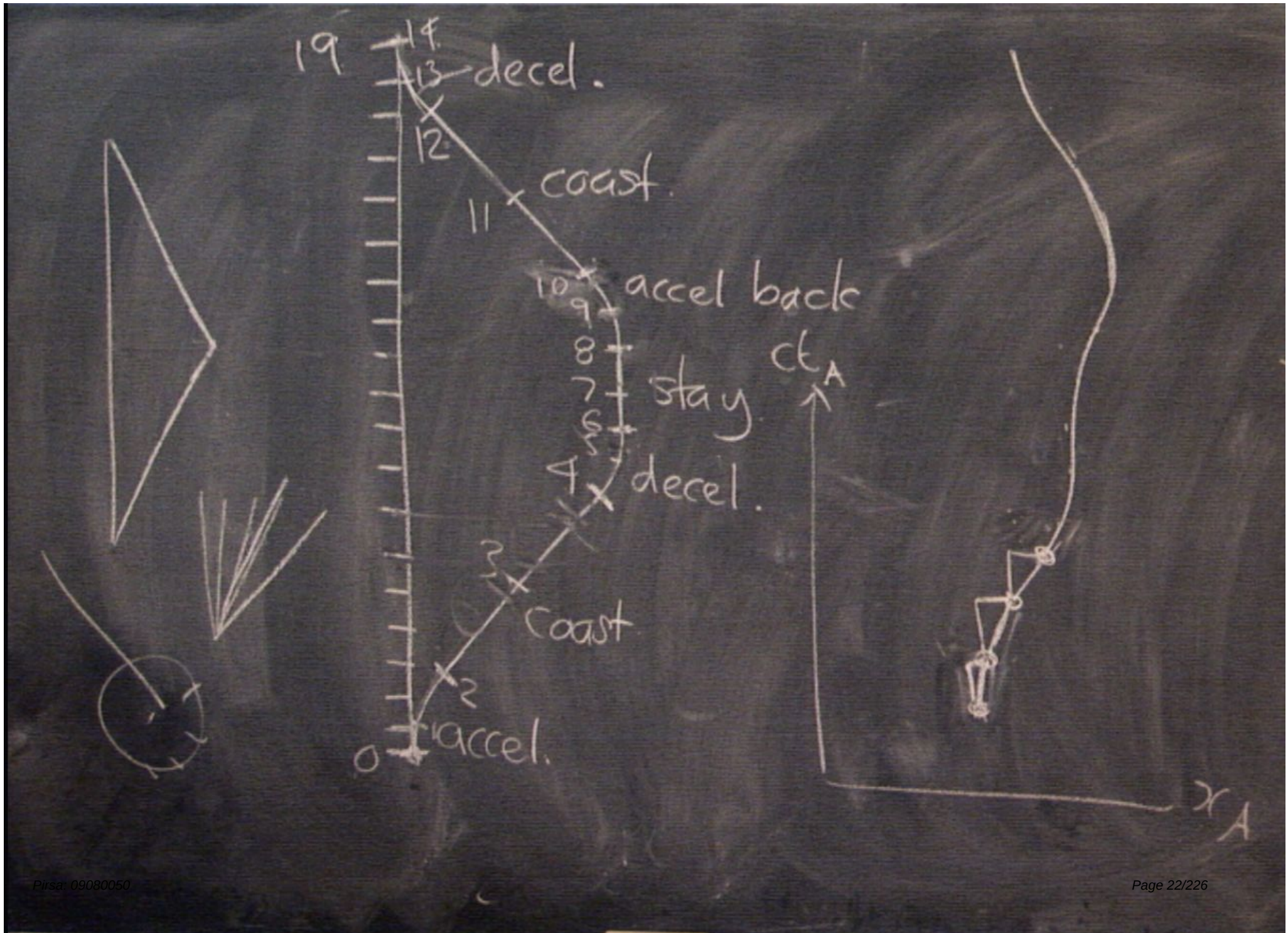

19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
stay.
6
5
4
decel.
3
coast
2
accel.
0

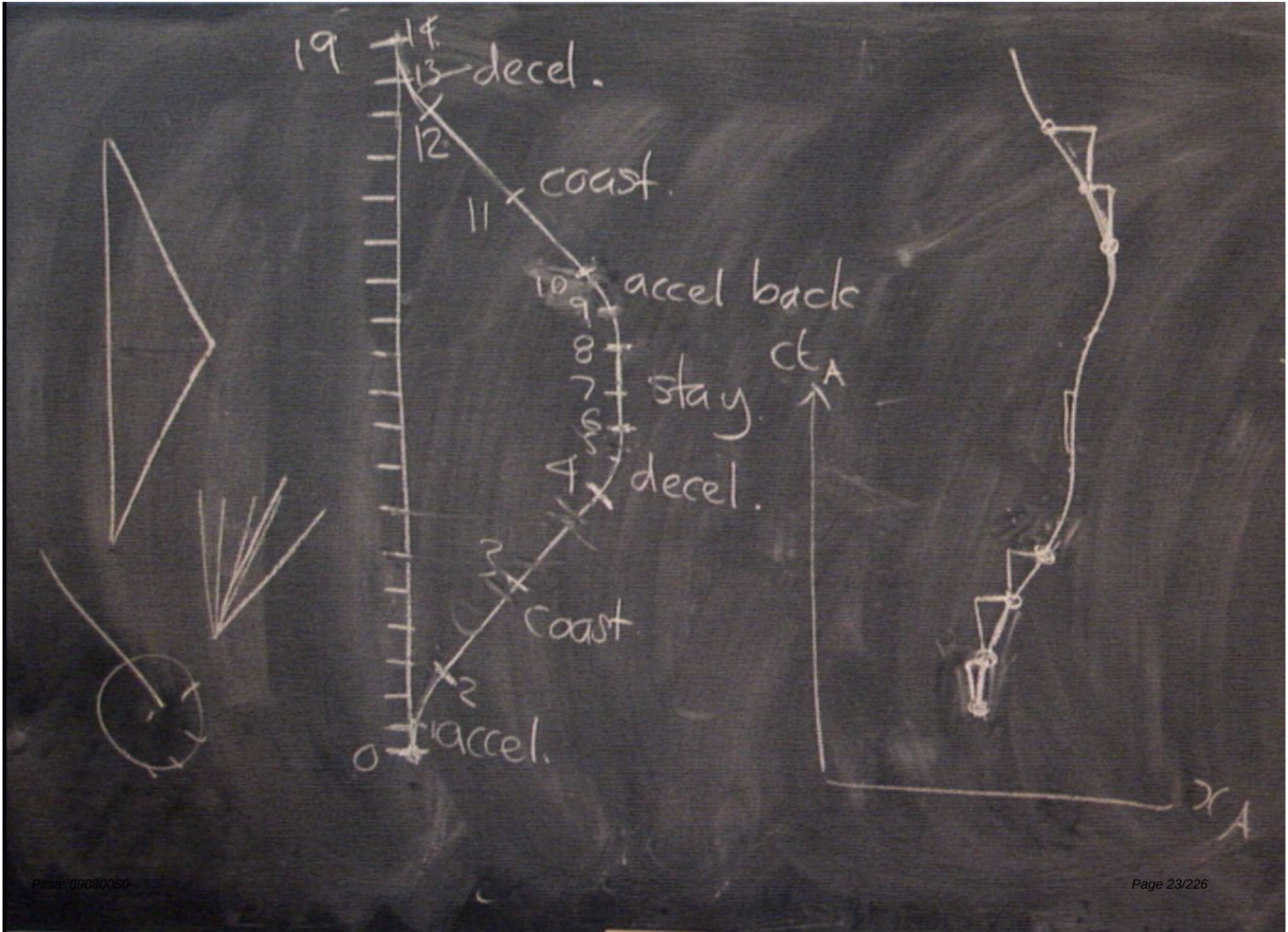

19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
stay
6
5
4
decel.
3
coast
2
1
accel.
0


19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
stay
6
5
4
decel.
3
coast
2
1
accel.
0
x_A

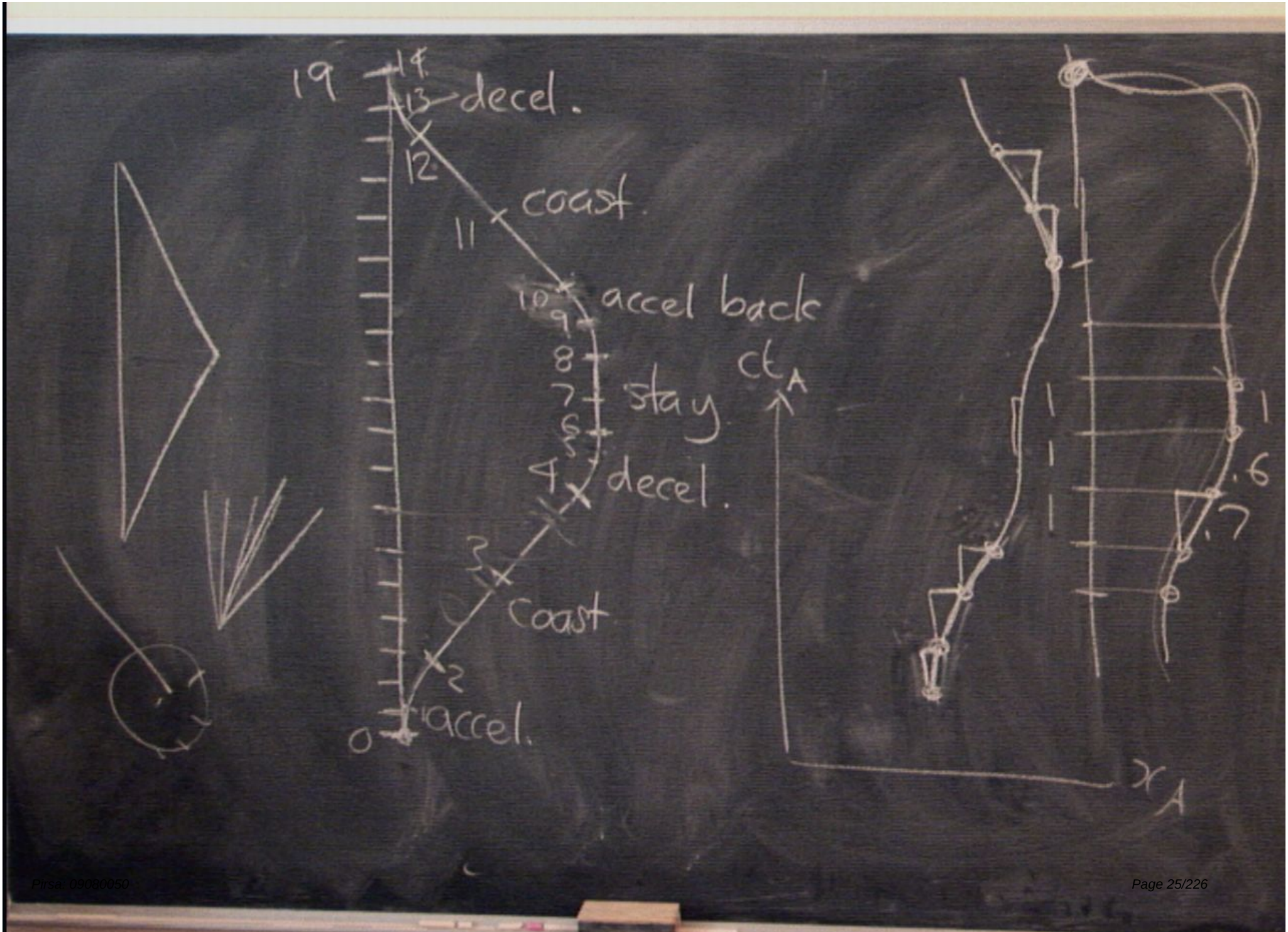

19
decel.
coast.
accel back
ct_A
x_A

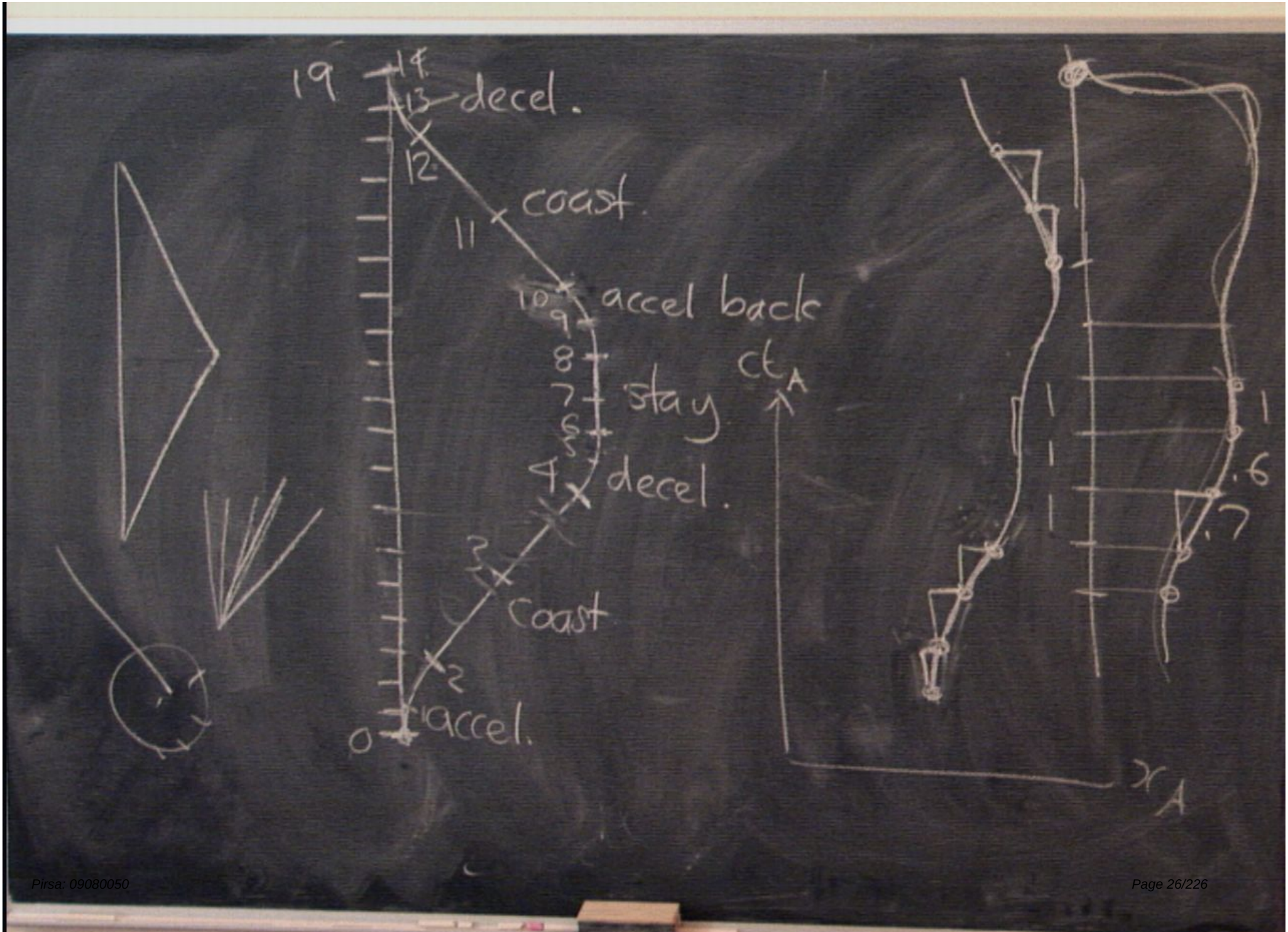

19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
stay
6
5
4
decel.
3
2
coast
el.
ct_A
x_A

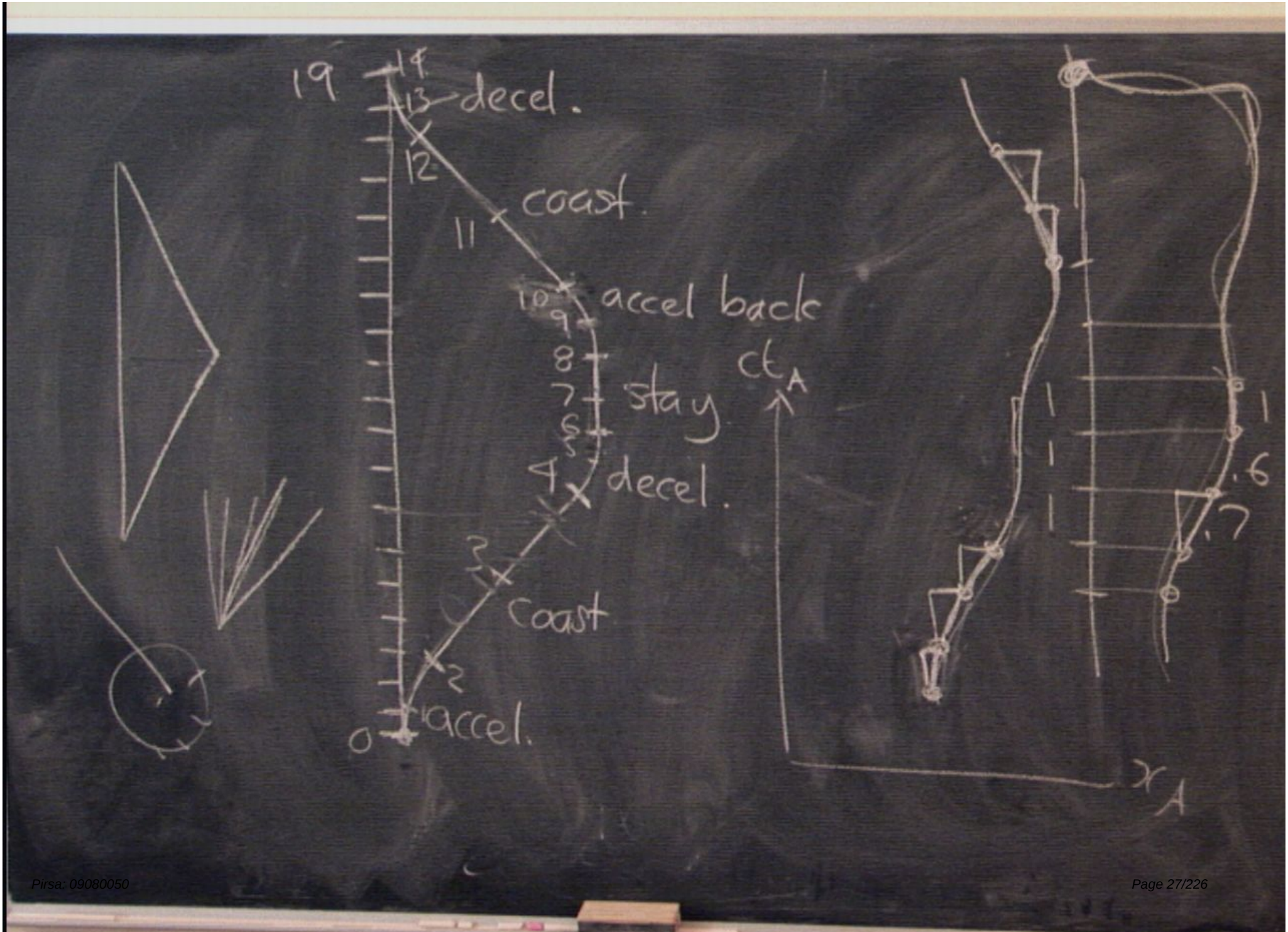

19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
stay
6
5
4
decel.
3
coast
2
accel.
0
x_A

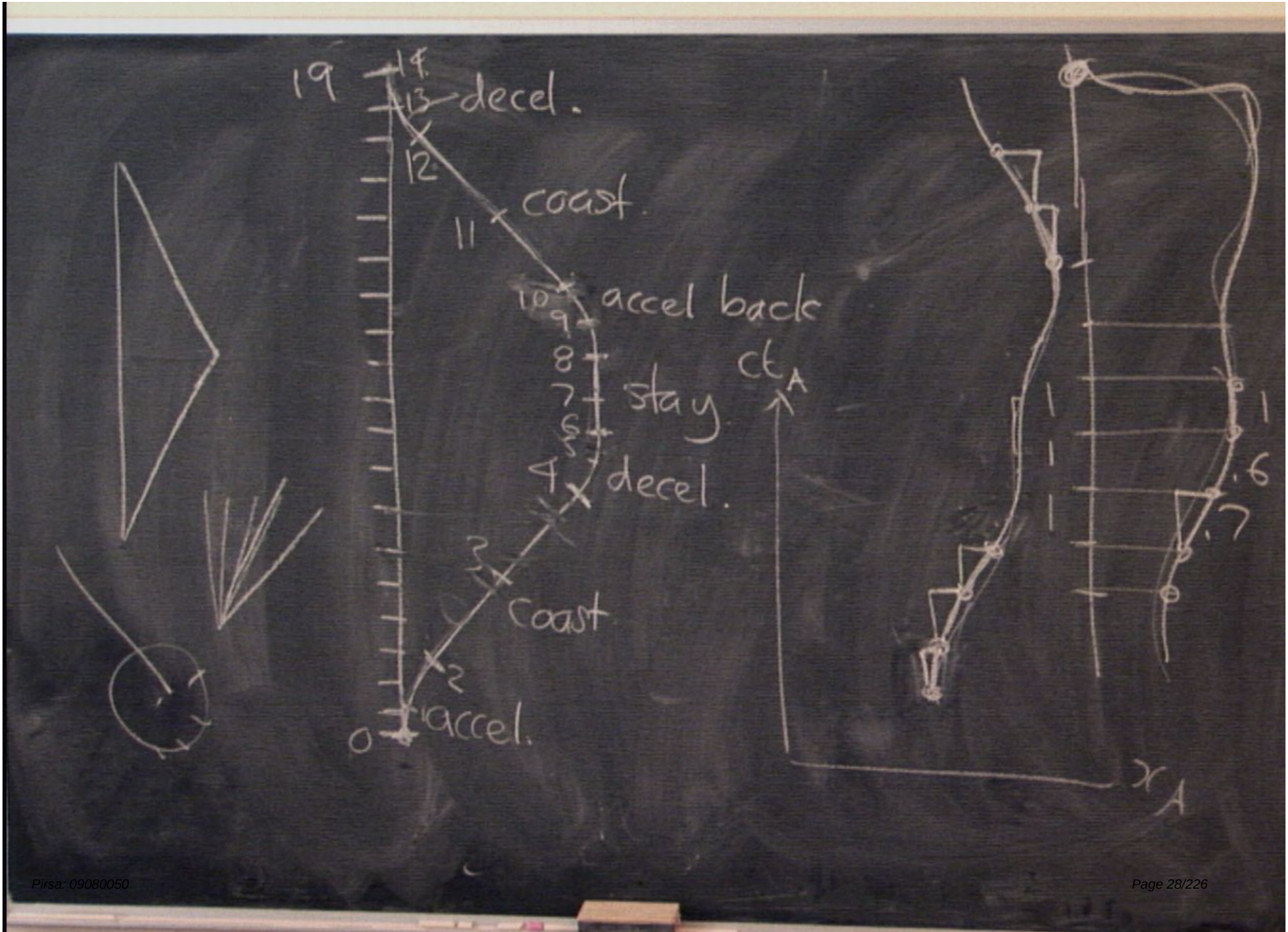

19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
6
5
stay.
4
decel.
3
coast
2
accel.
0
x_A


19
decel.
coast.
accel back
stay
decel.
ct_A
x_A


19
14
13
decel.
12
coast.
11
10
accel back
9
8
7
6
5
stay
4
decel.
3
coast
2
accel.
0
x_A
t_A
1.6
1.7

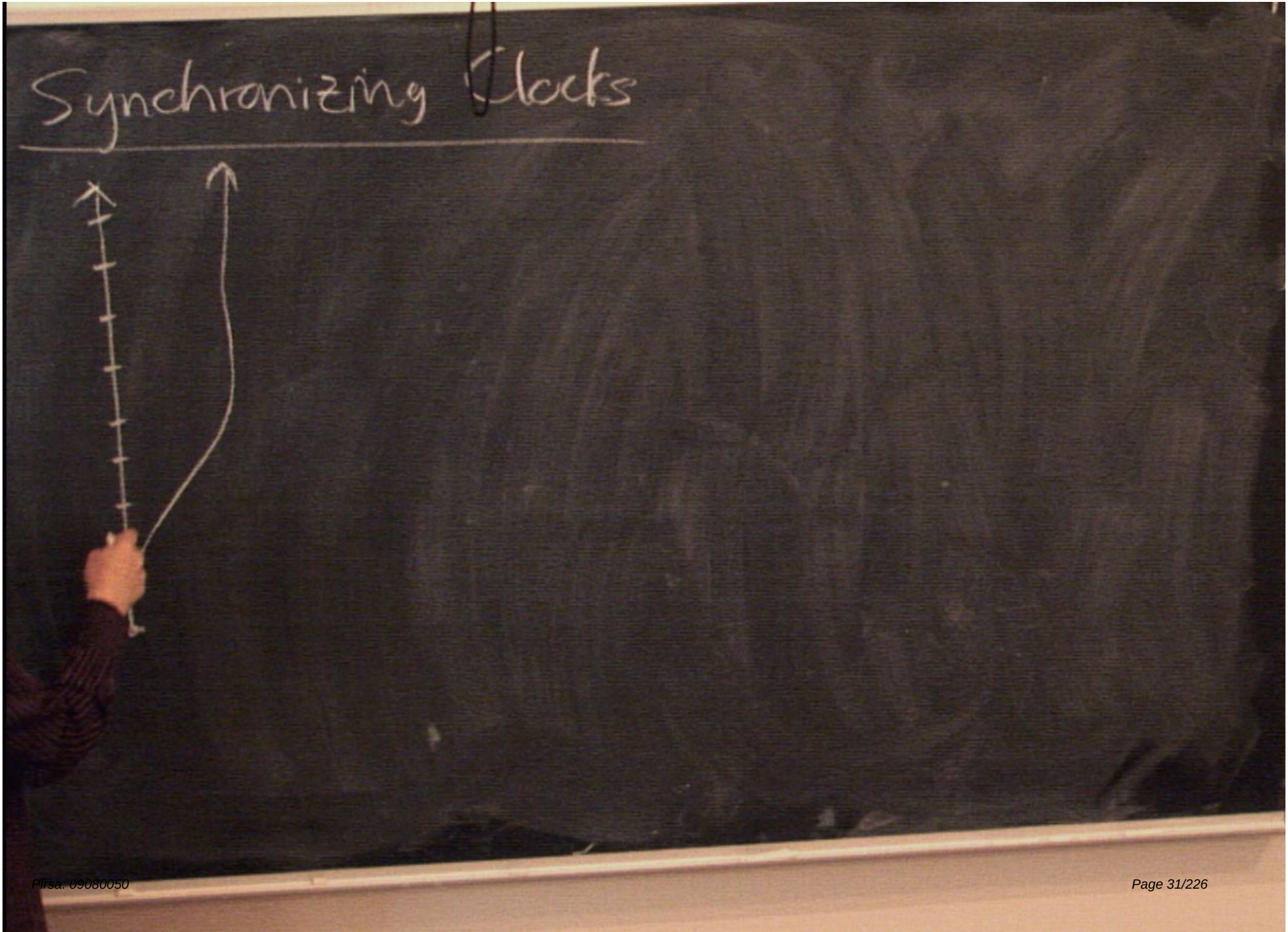

19
decel.
coast.
accel back
stay
decel.
coast
accel.
0
ct
A
x
A

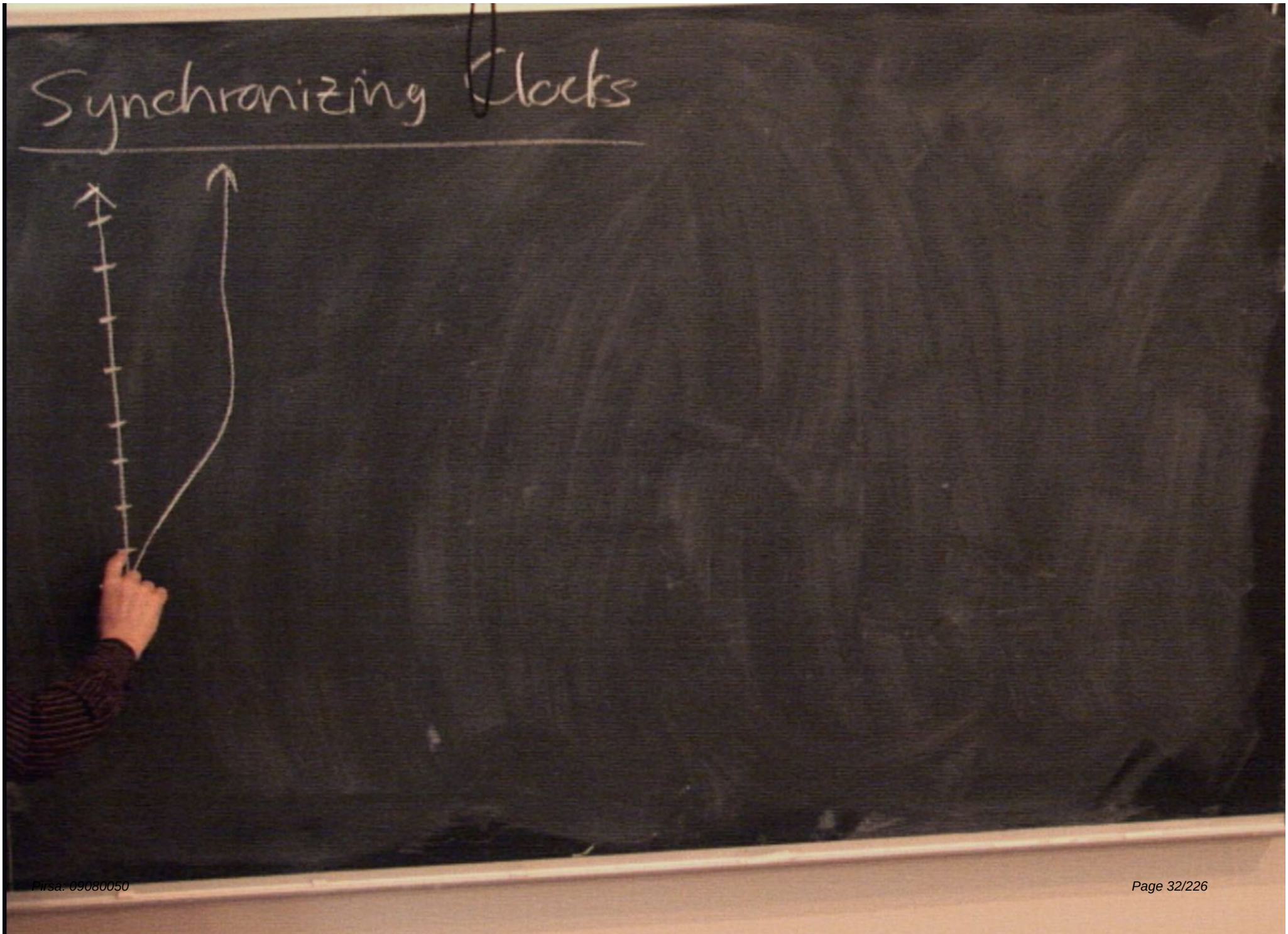

19
decel.
coast.
accel back
stay
decel.
coast
accel.
ct_A
x_A


19
decel.
coast.
accel back
stay
decel.
Coast
accel.
ct_A
x_A

Synchronizing Clocks


Synchronizing Clocks

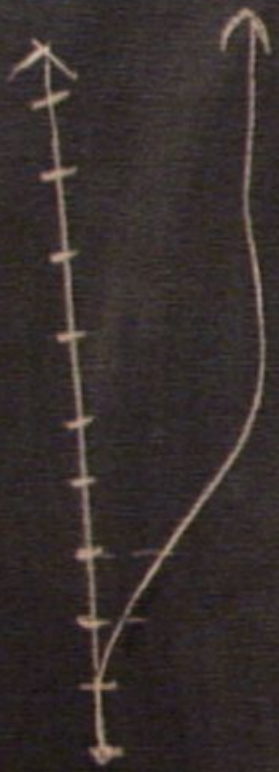

Synchronizing Clocks


Synchronizing Clocks

Synchronizing Clocks



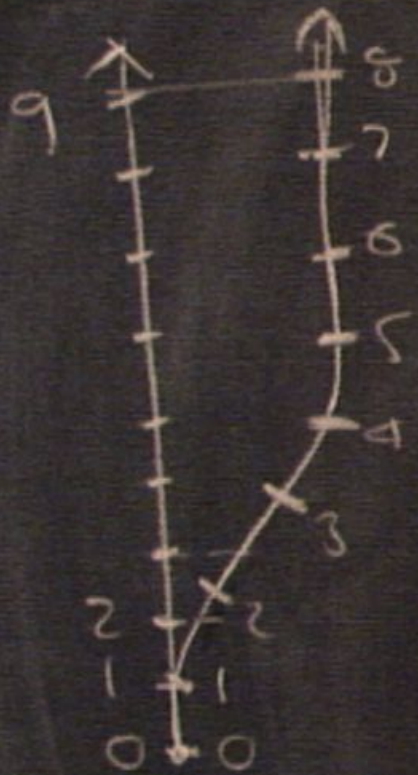
Synchronizing Clocks



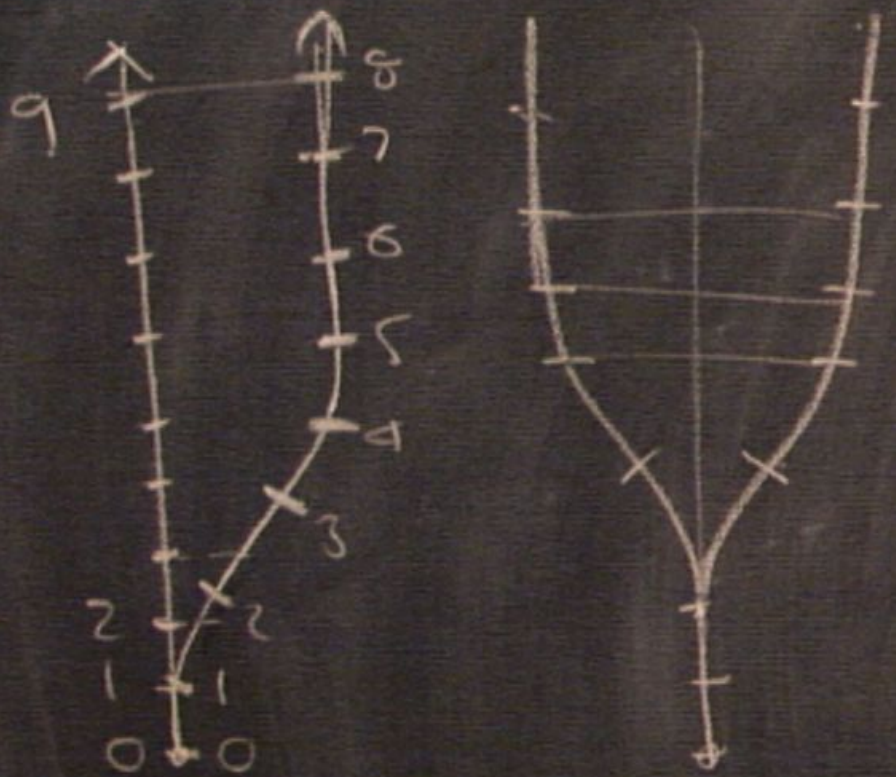
Synchronizing Clocks



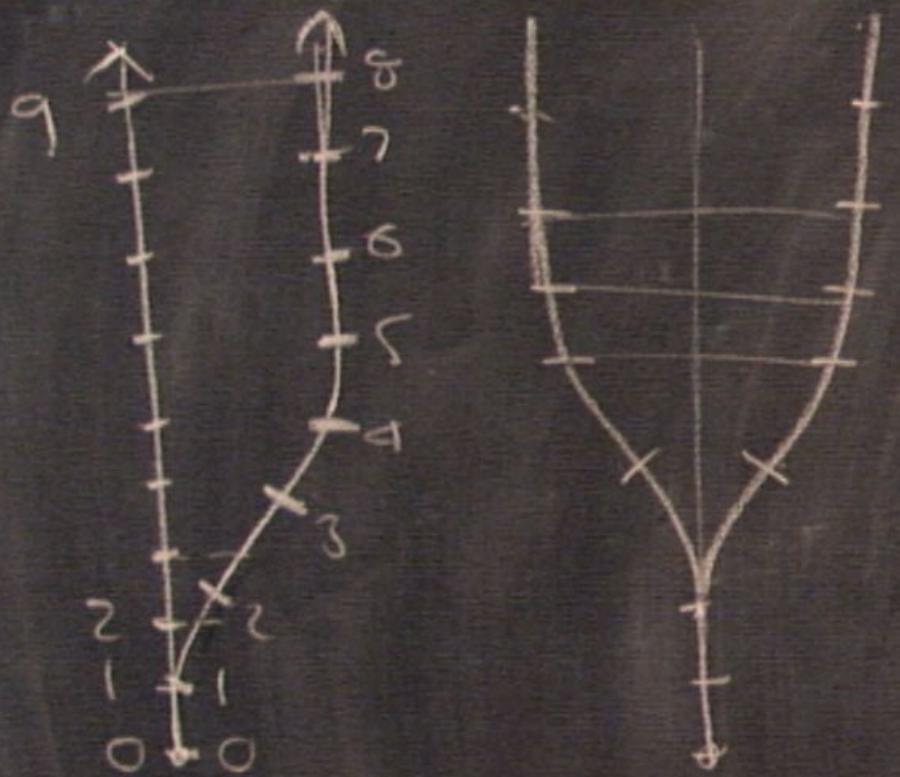
Synchronizing Clocks



Synchronizing Clocks

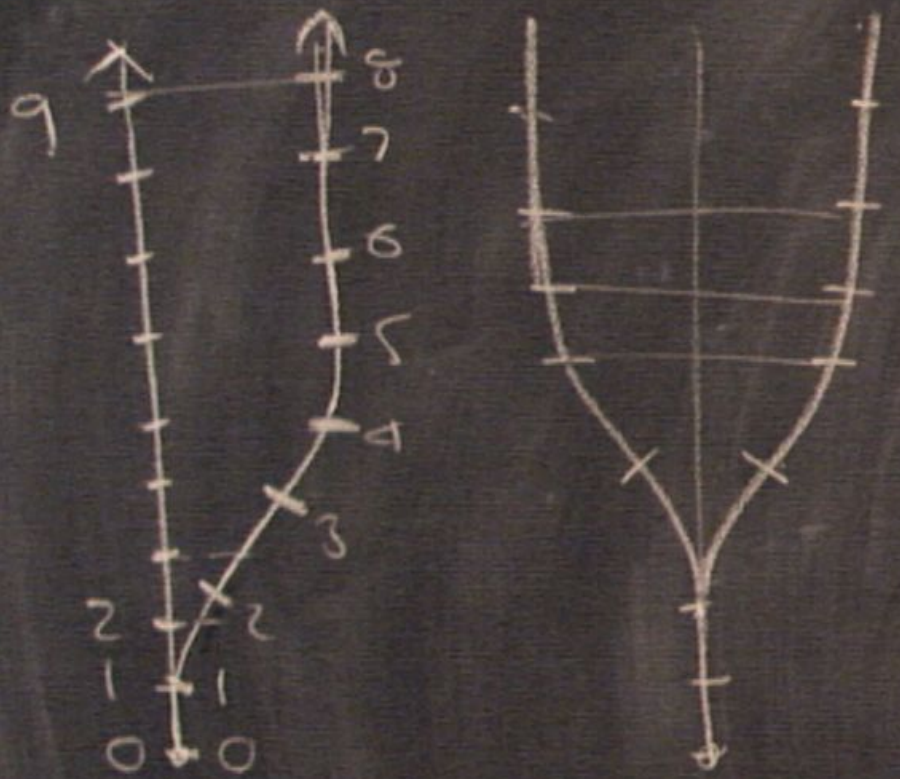


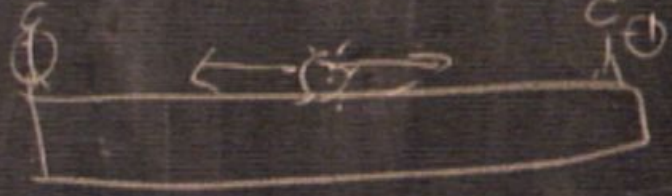
Synchronizing Clocks



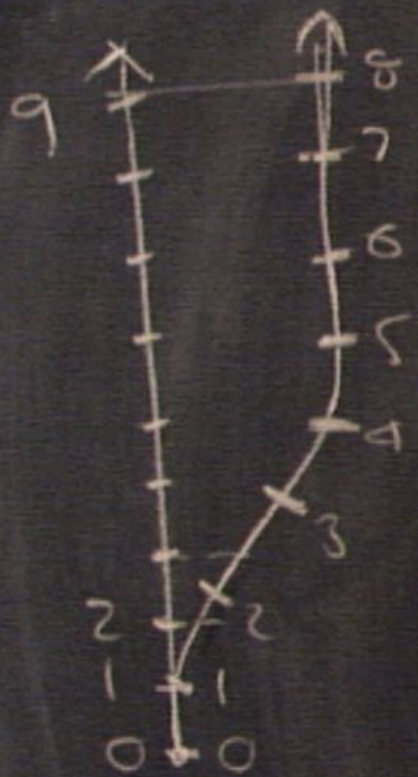


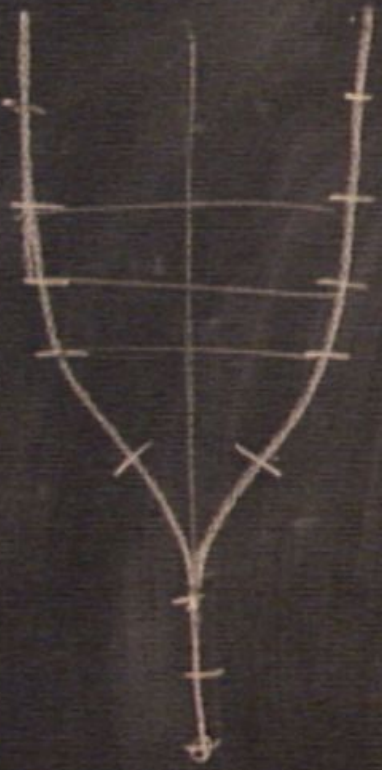
Synchronizing Clocks

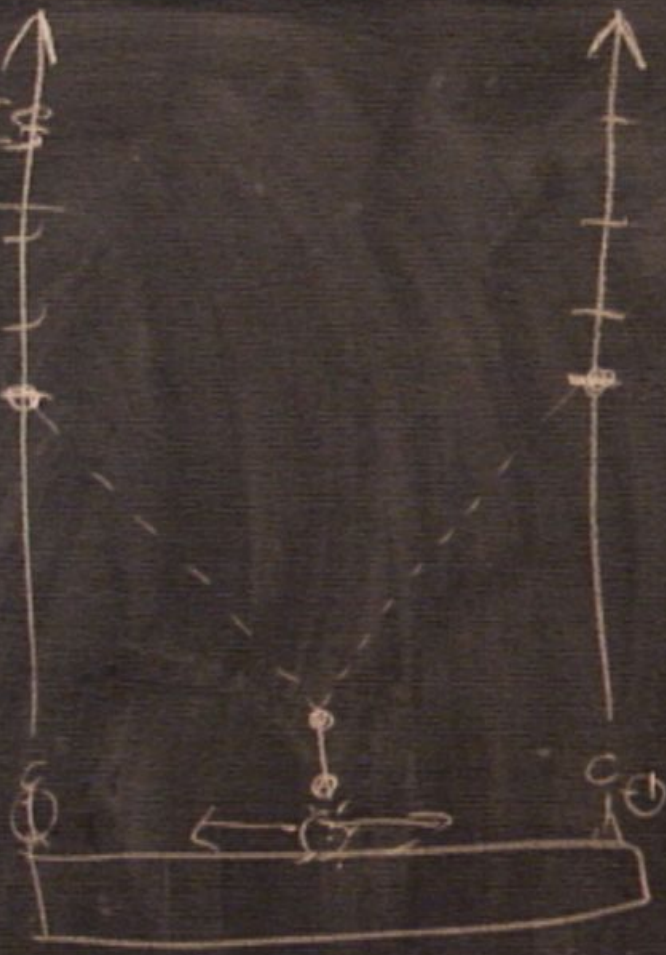


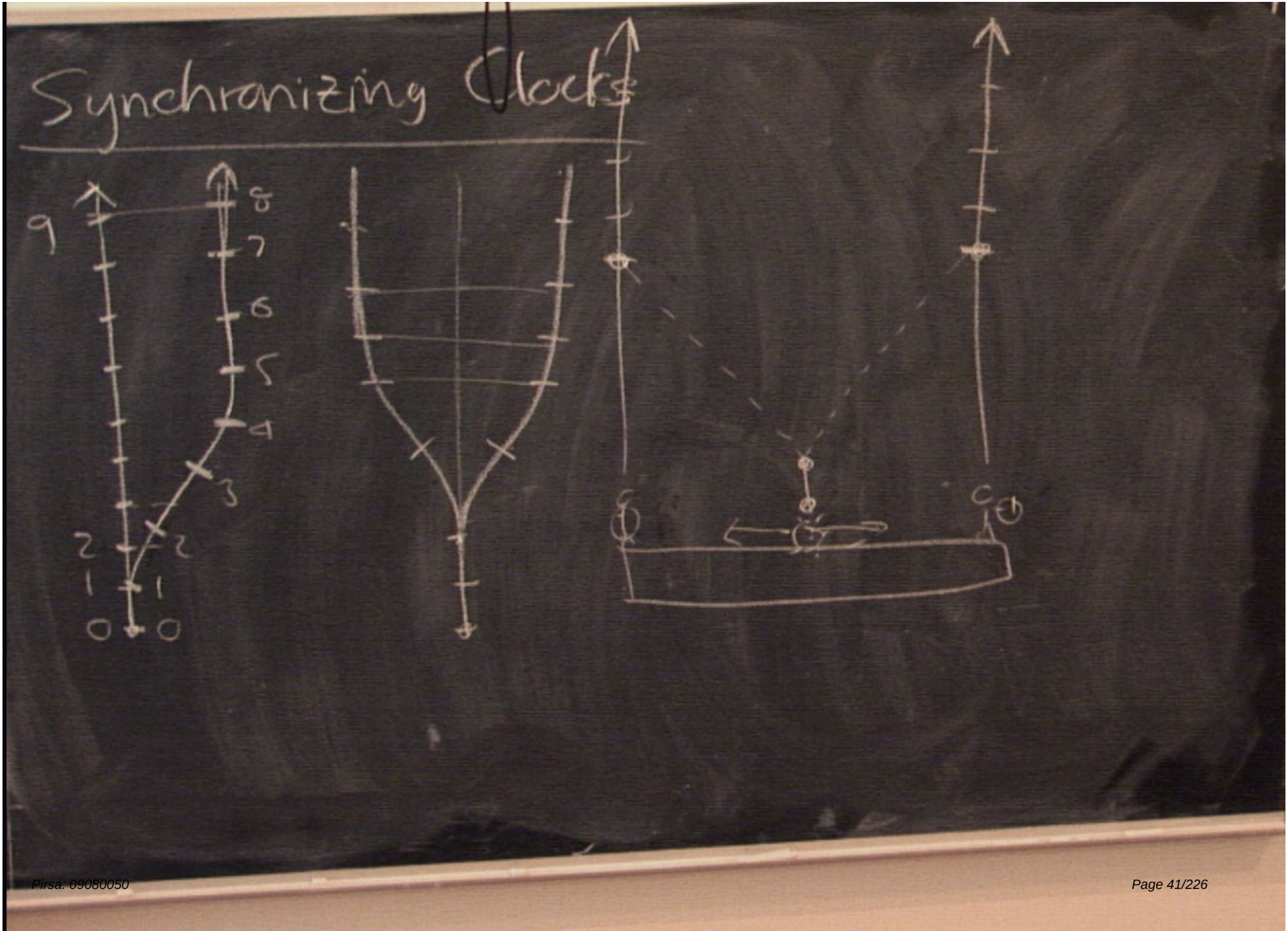


Synchronizing Clocks







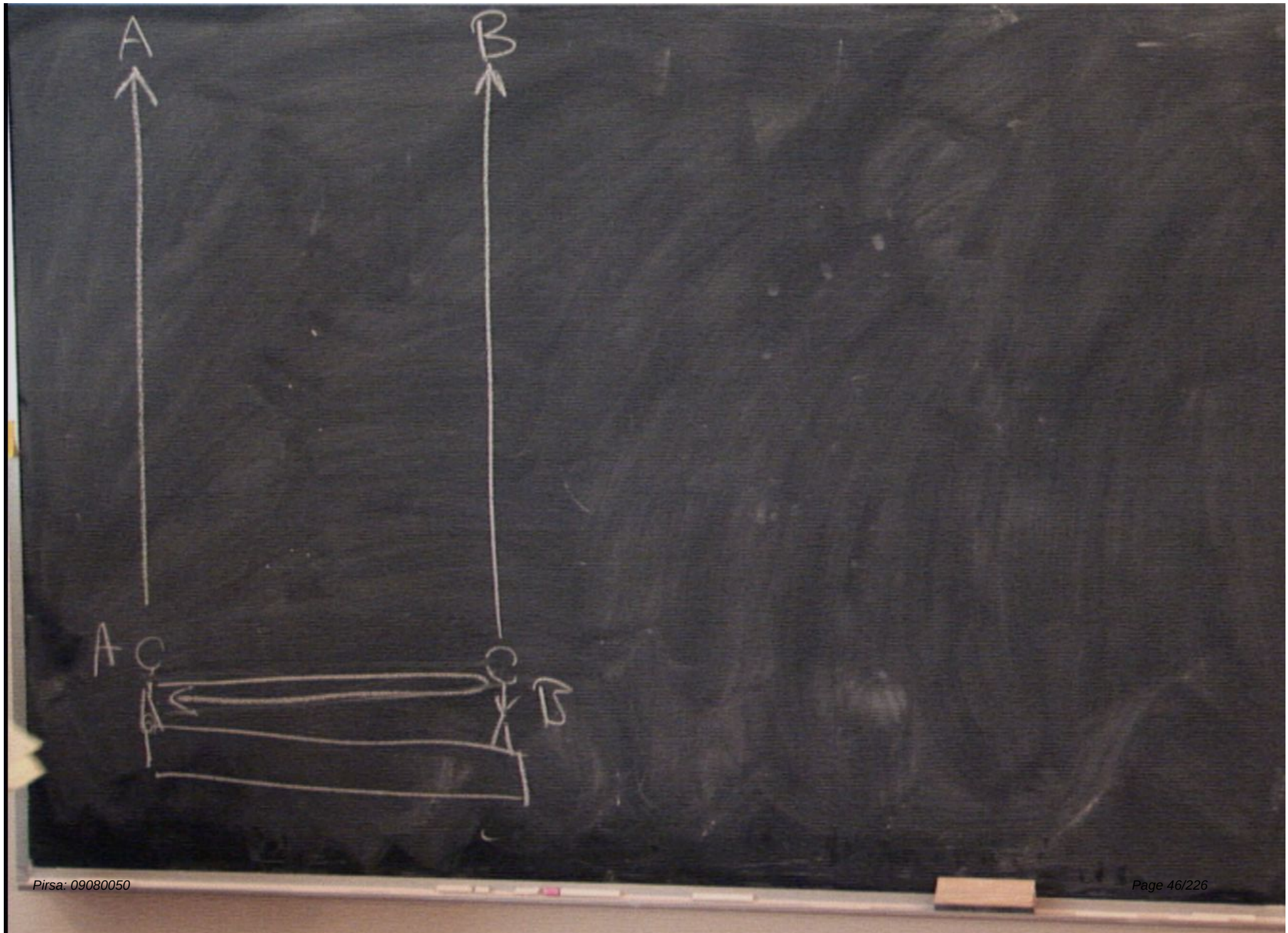

Synchronizing Clocks
9
8
7
6
5
4
3
2
1
0
2
1
0

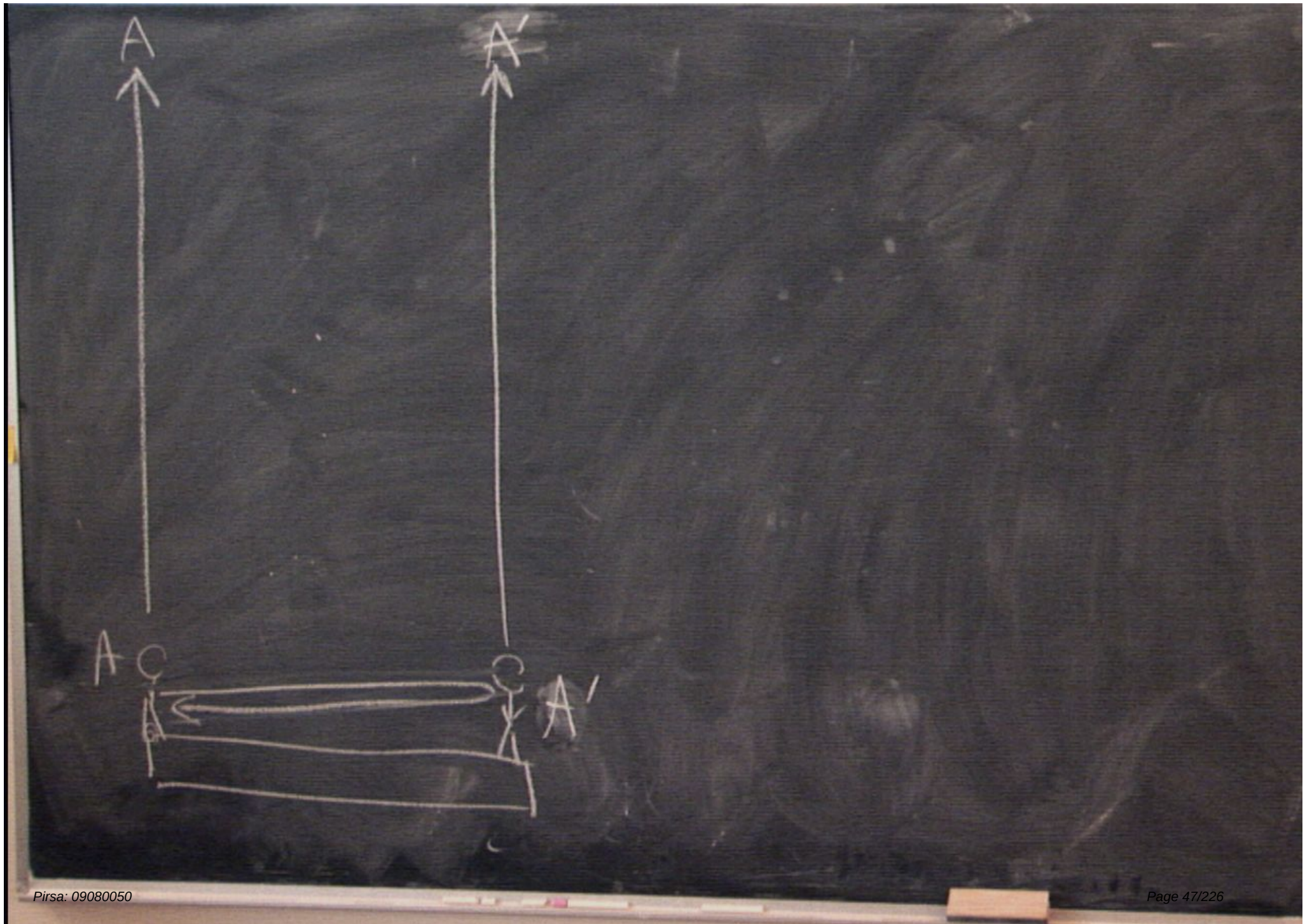


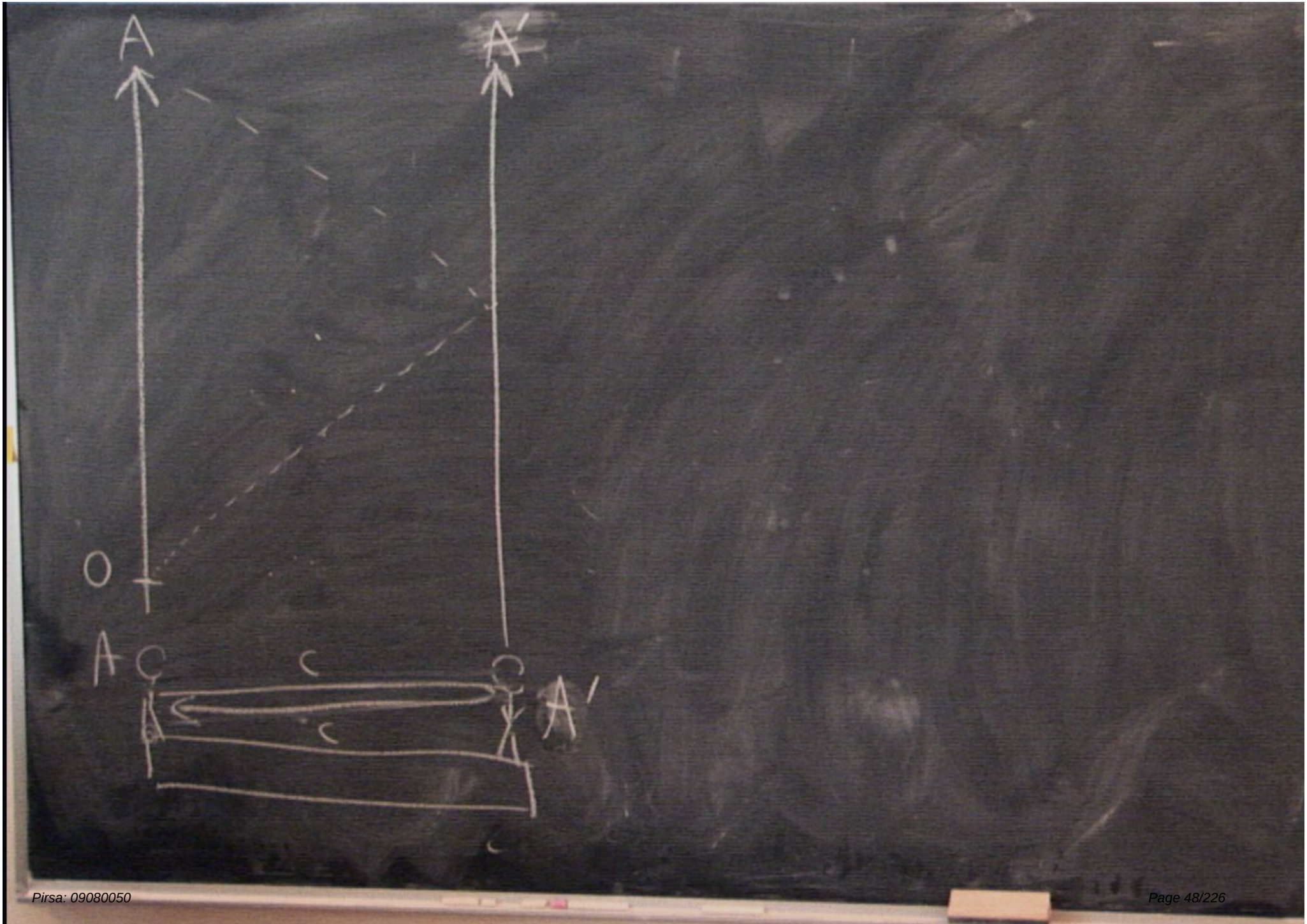

A
B

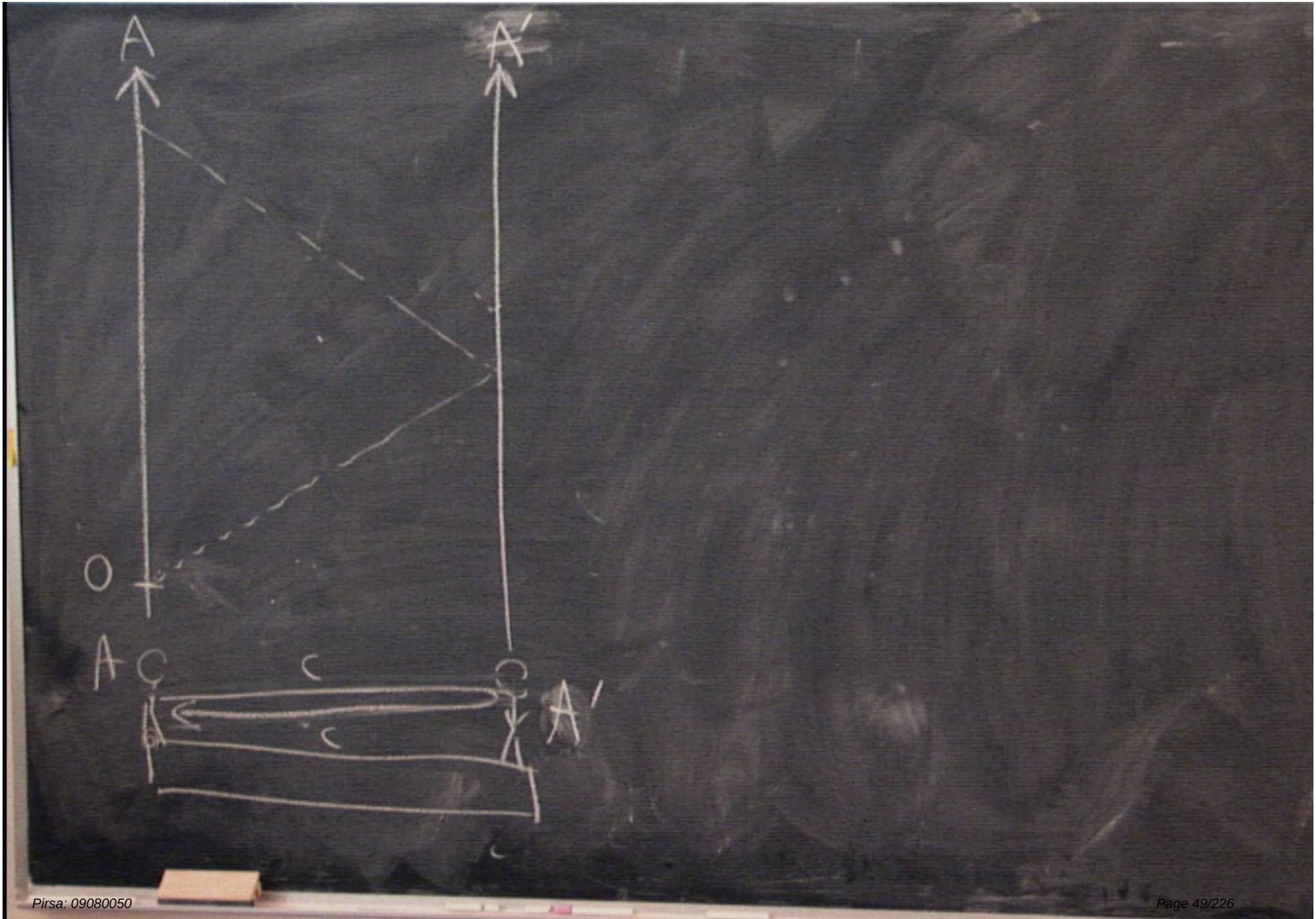

A
B

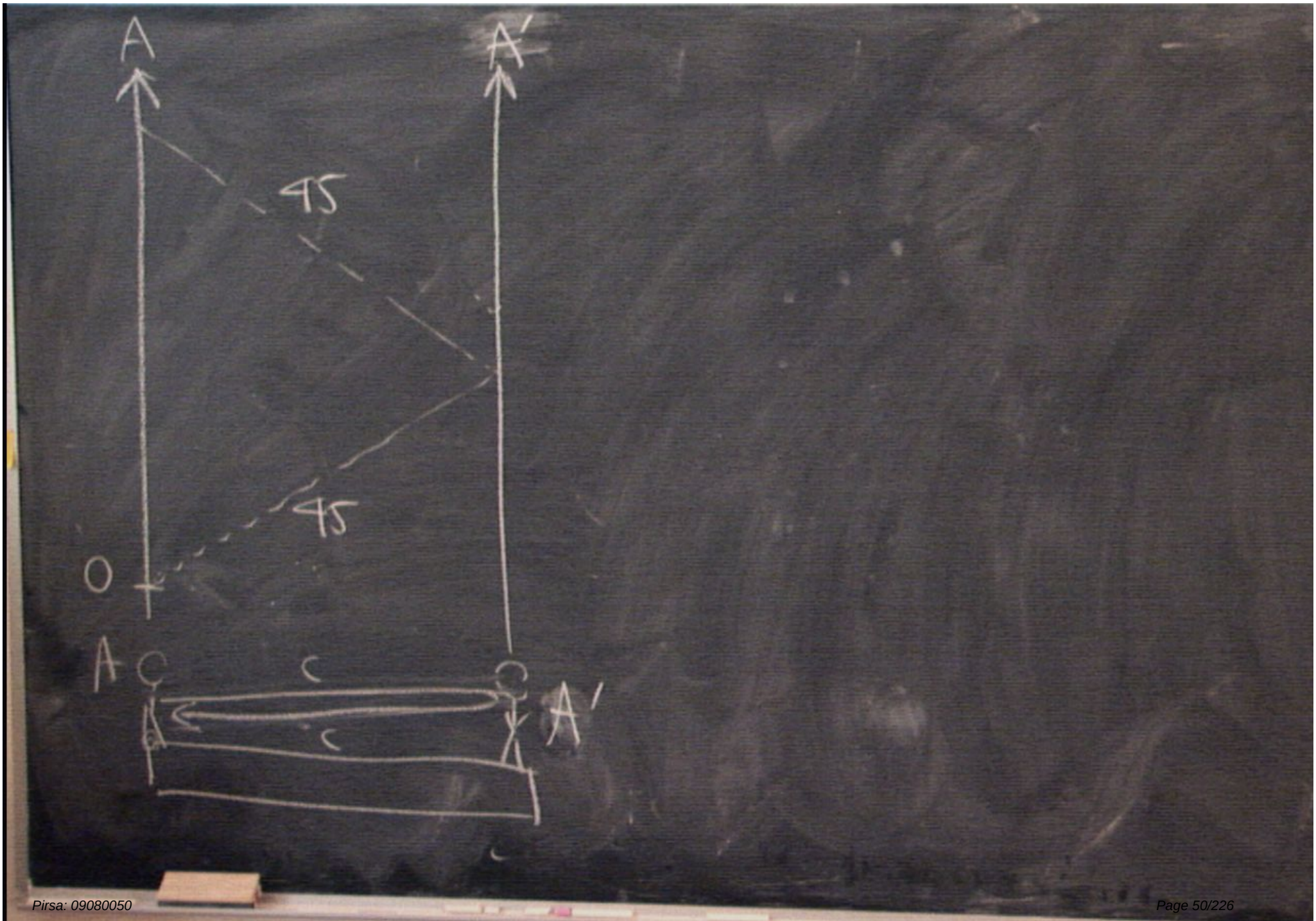

A
B

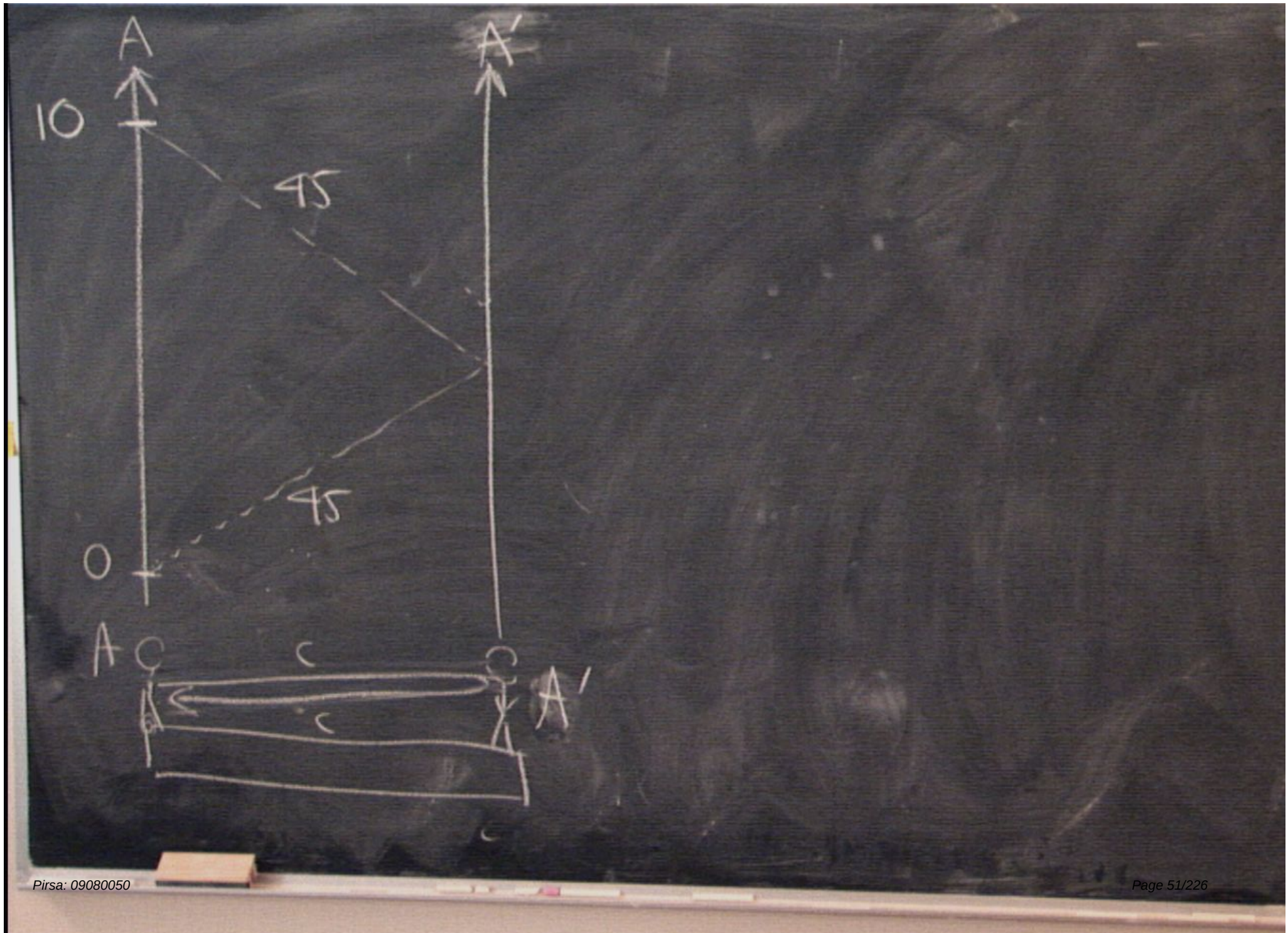

A
B
A
C
B

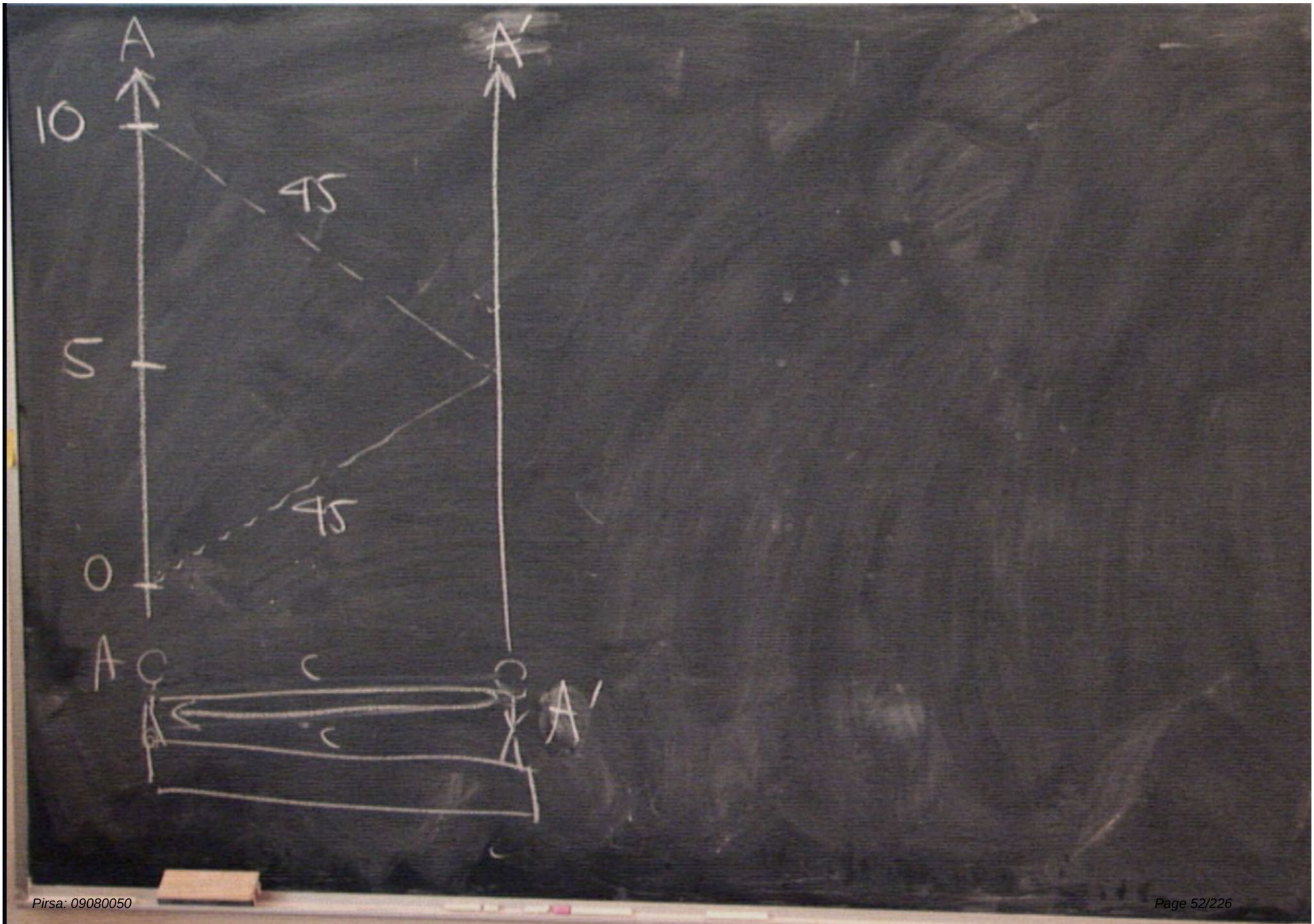

A
A'
A
C
A'

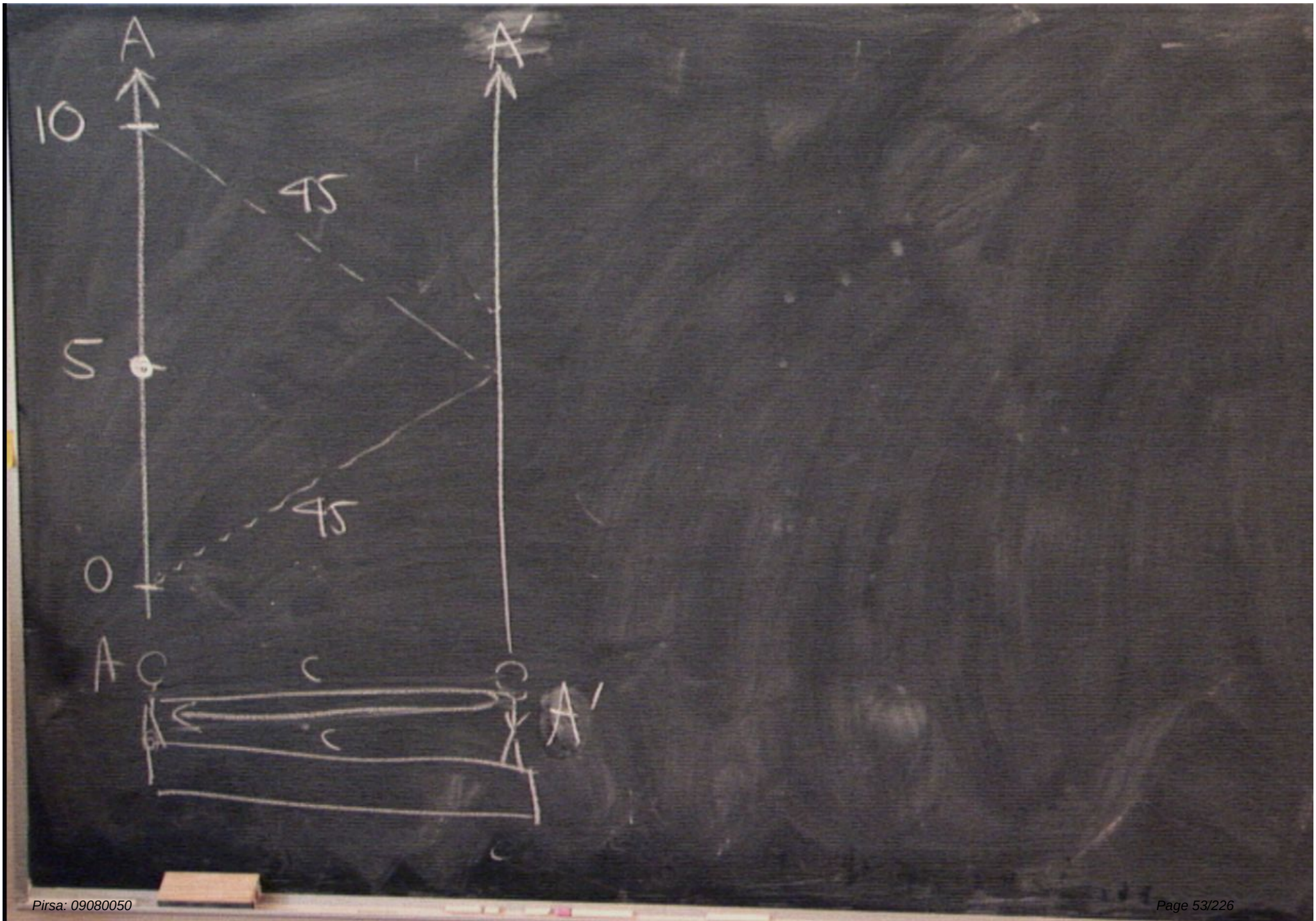

A
A'
O
A
A'

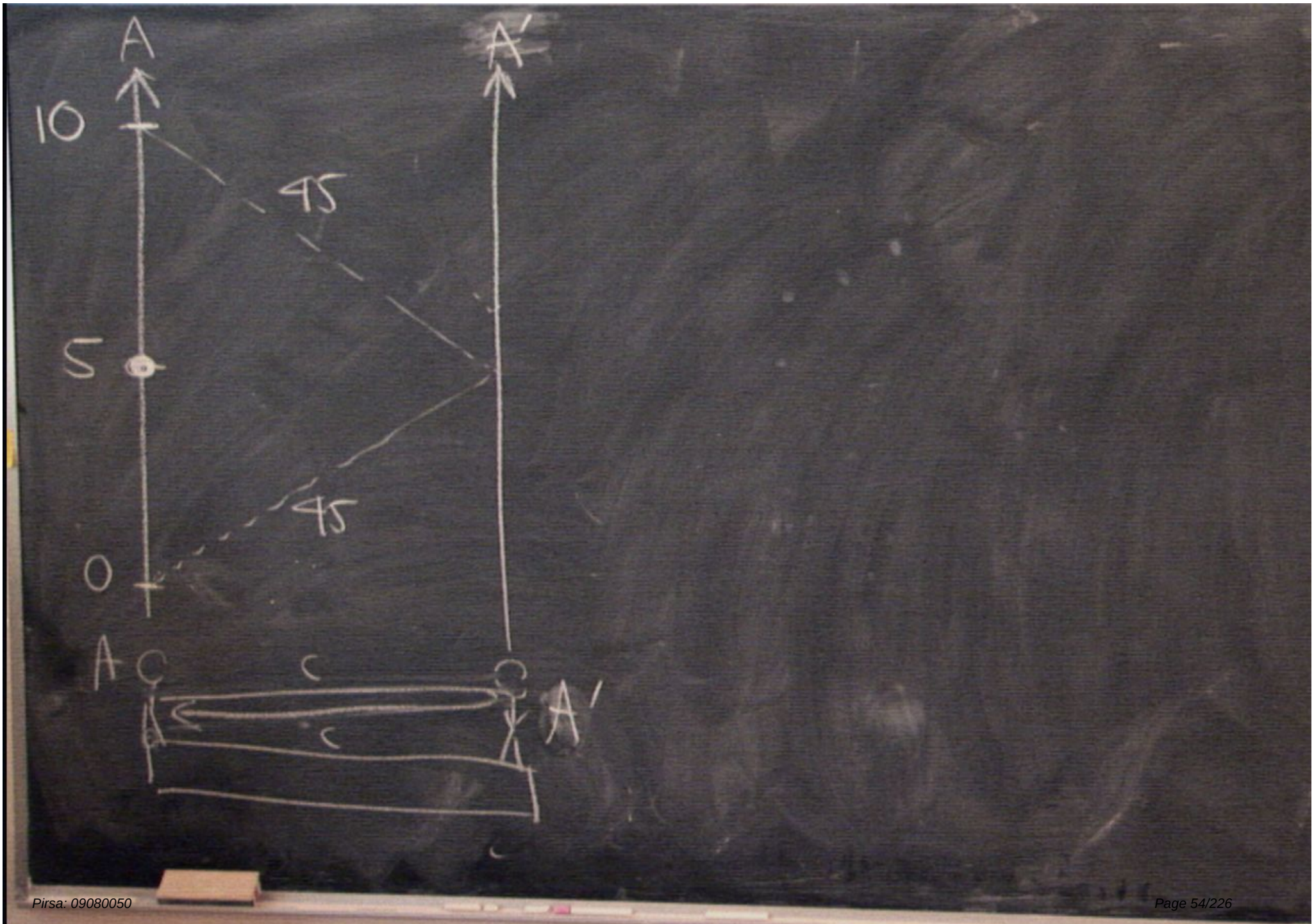

A
A'
O
A
A'

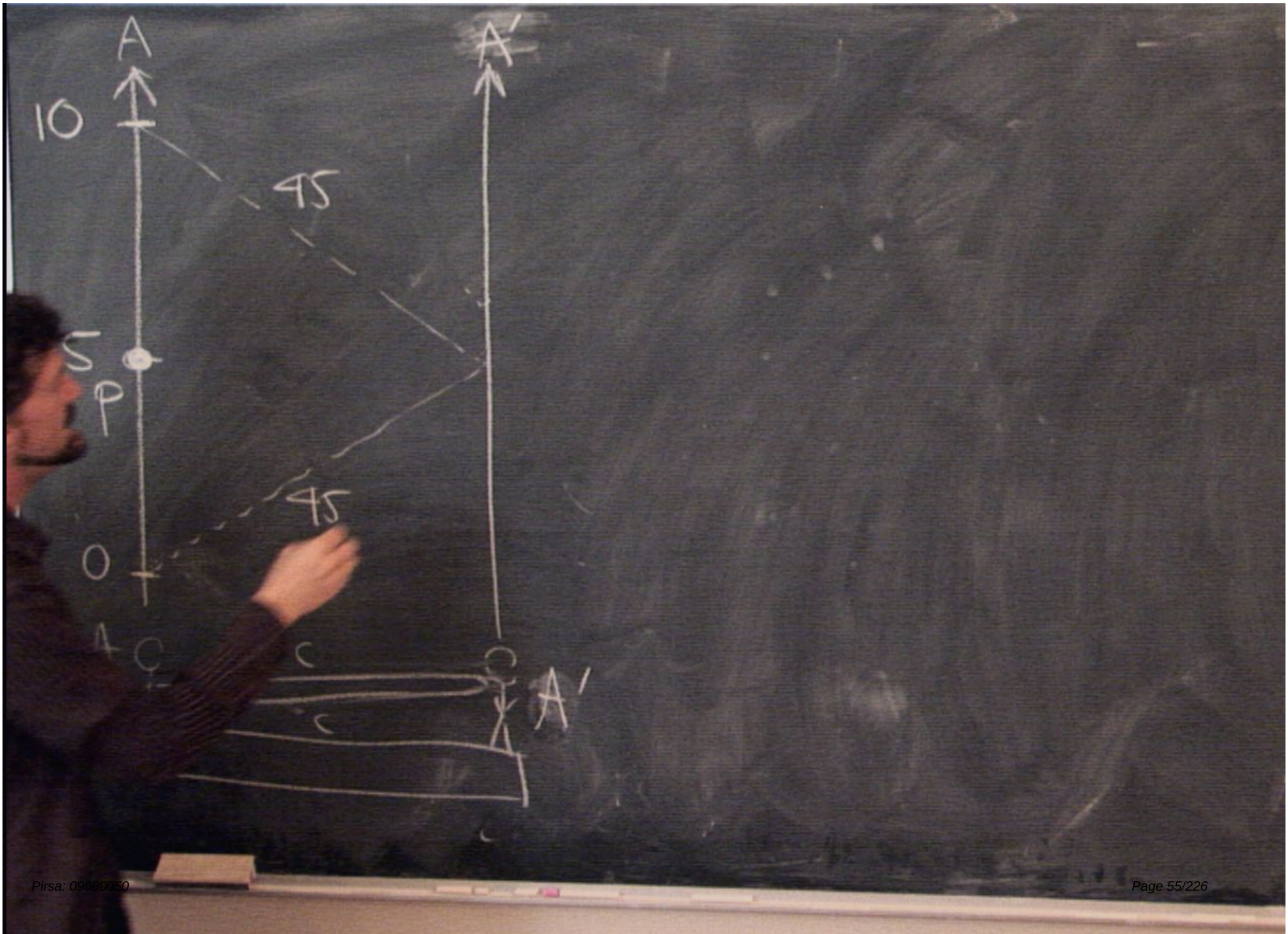

A
A'
45
45
O
A
A'

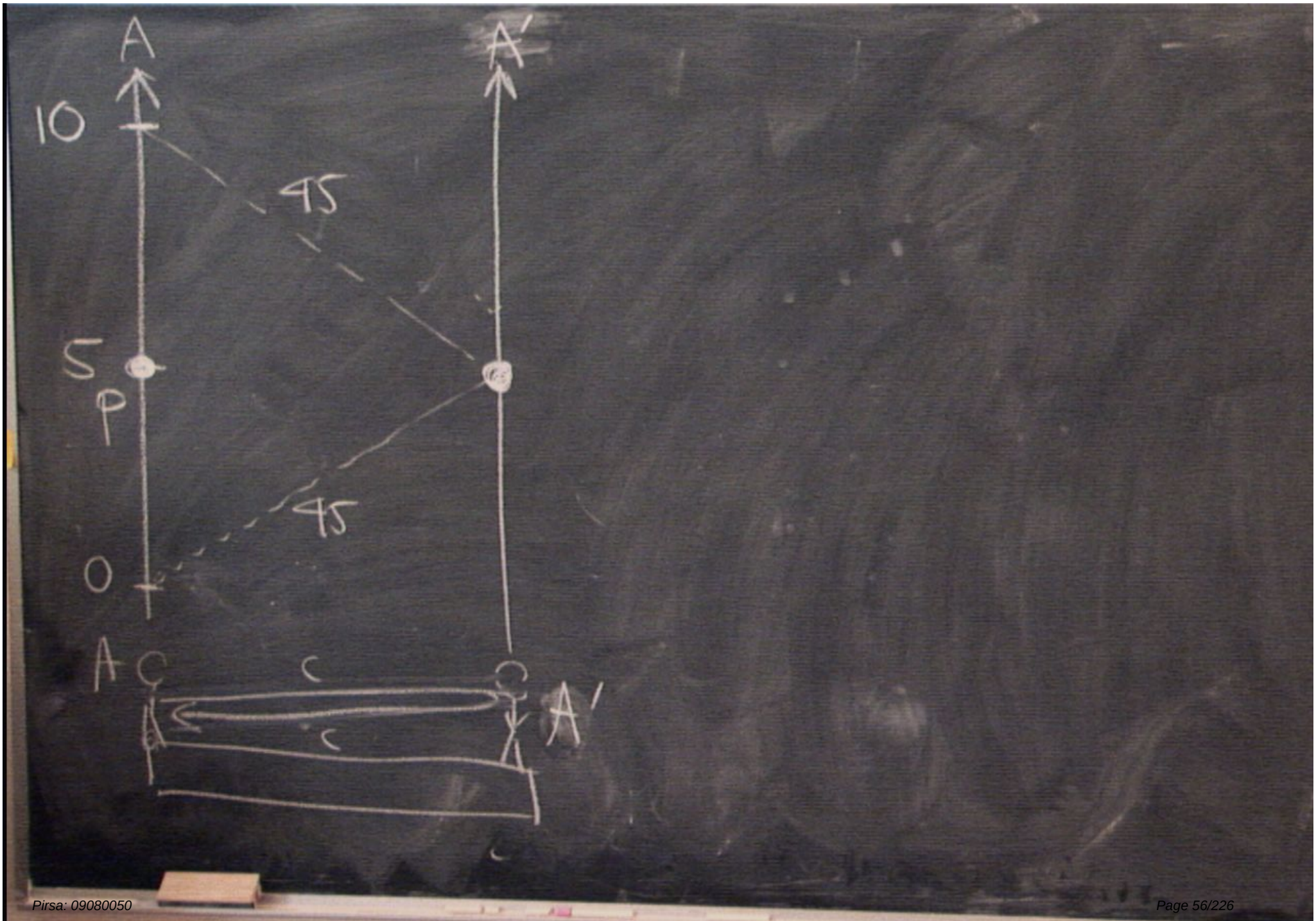

A
A'
10
45
45
O
A
A'

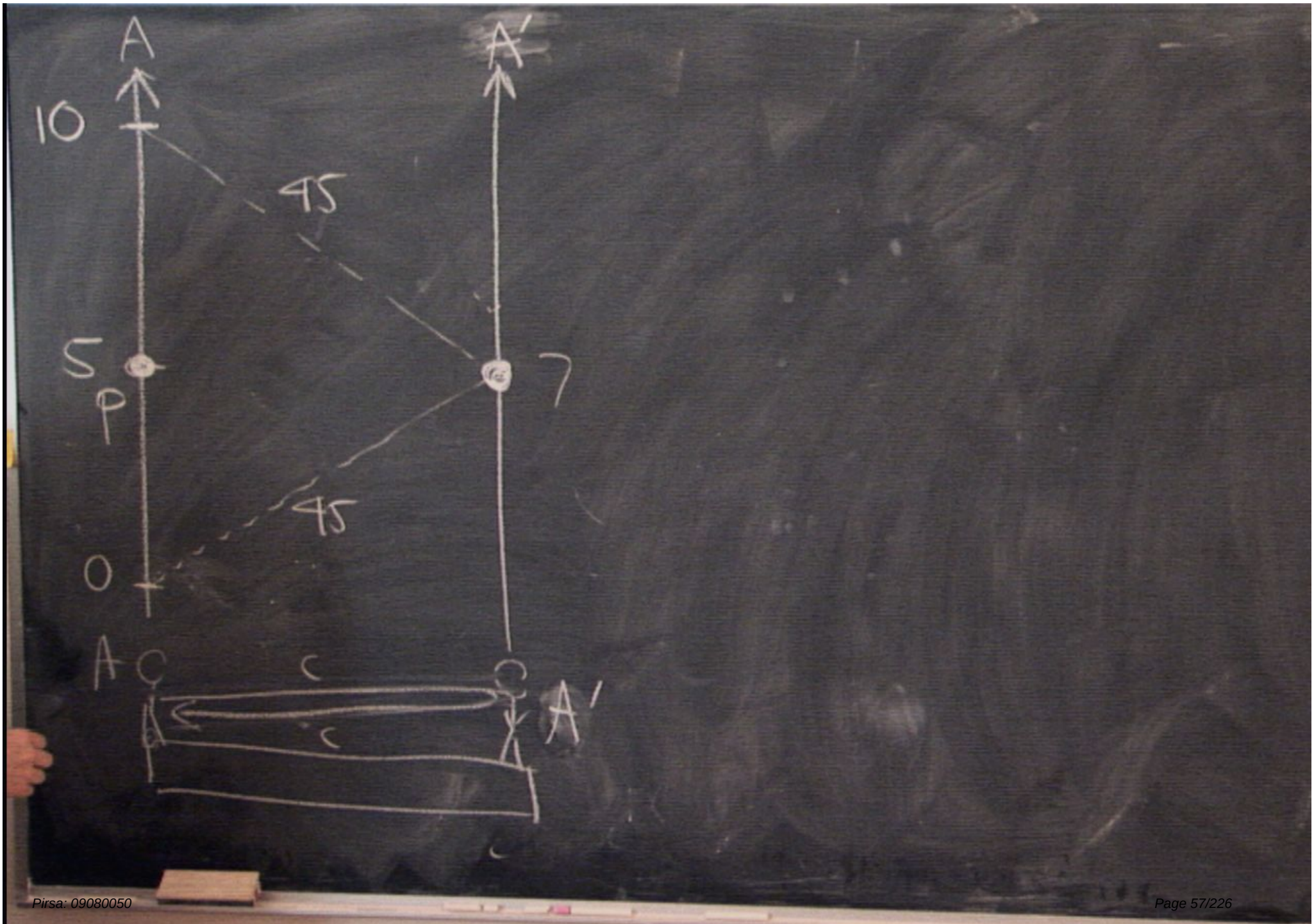

A
A'
10
45
5
45
0
A
A'

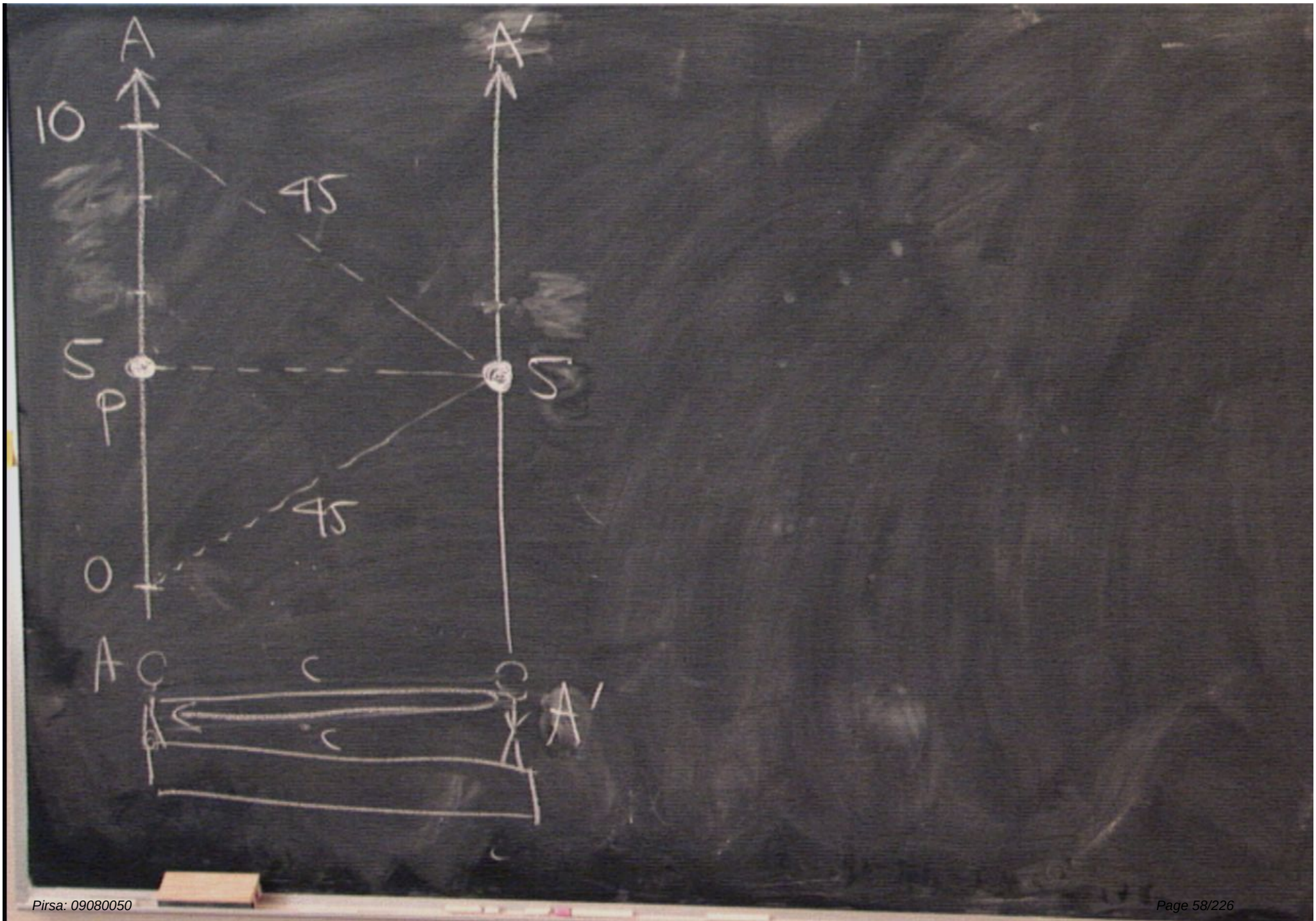

A
A'
10
45
5
45
0
A
C
C
C
C
A'

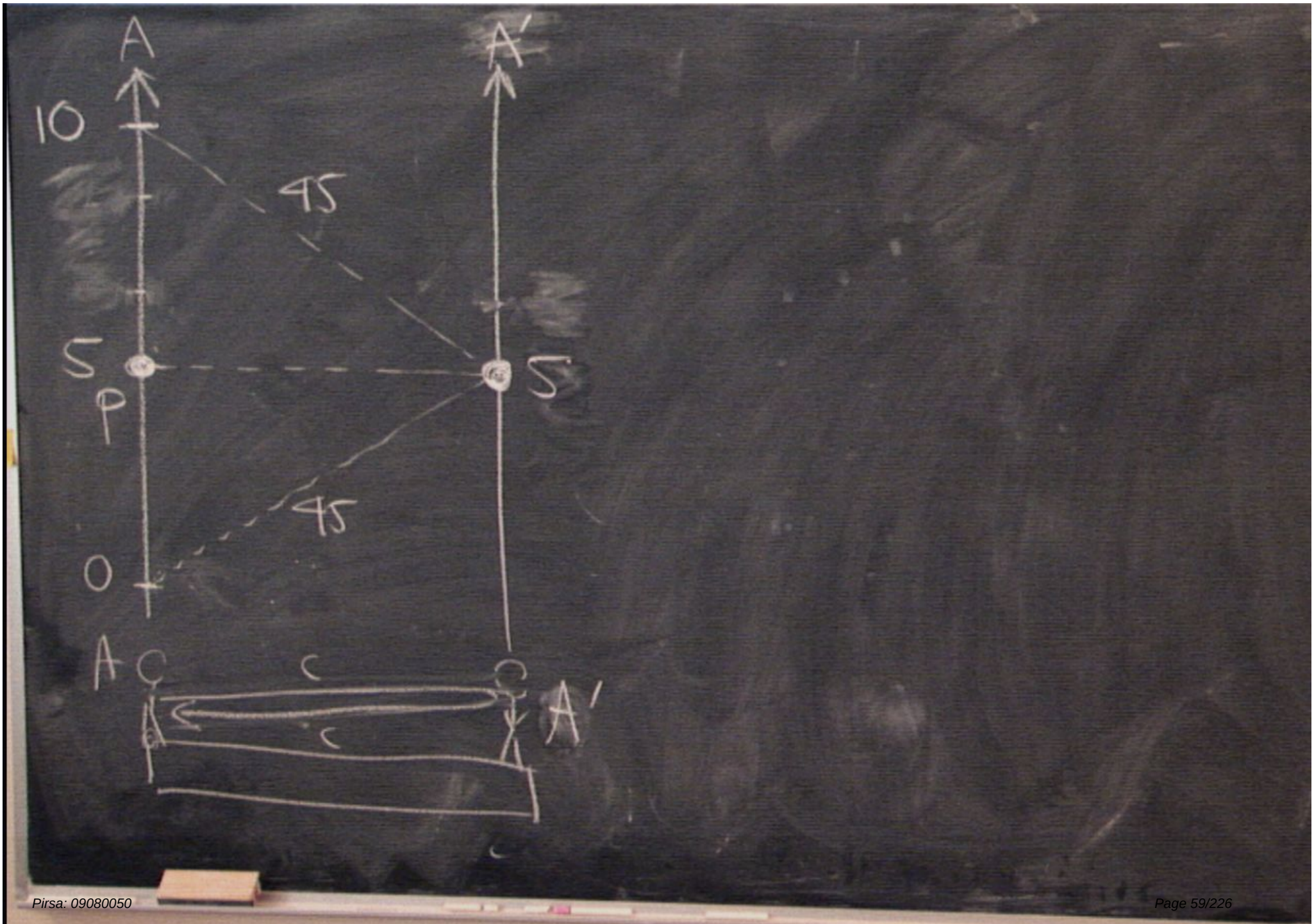

A
A'
10
95
5
95
0
A
A'

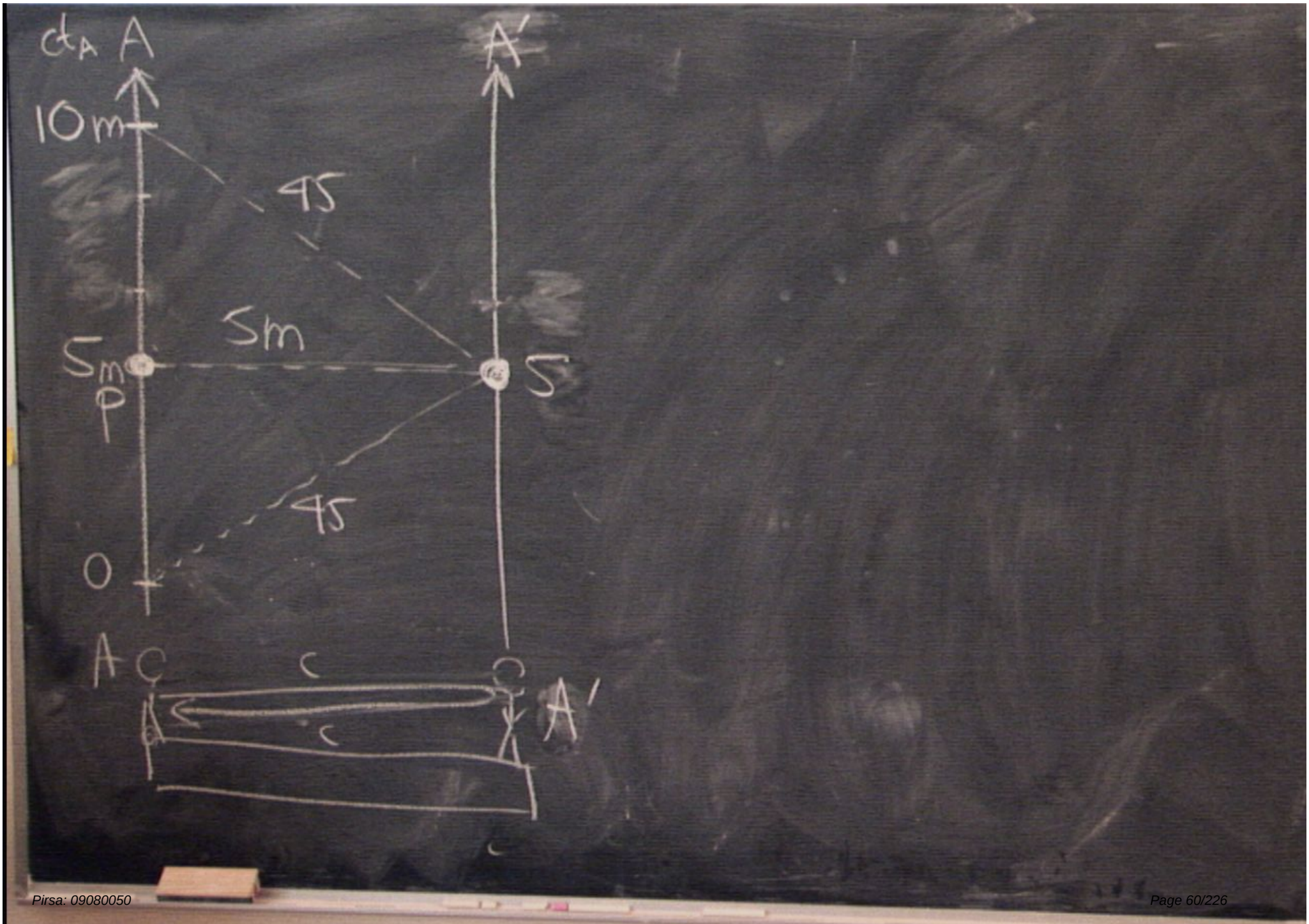

A
A'
10
45
S
P
45
0
A
C
A'

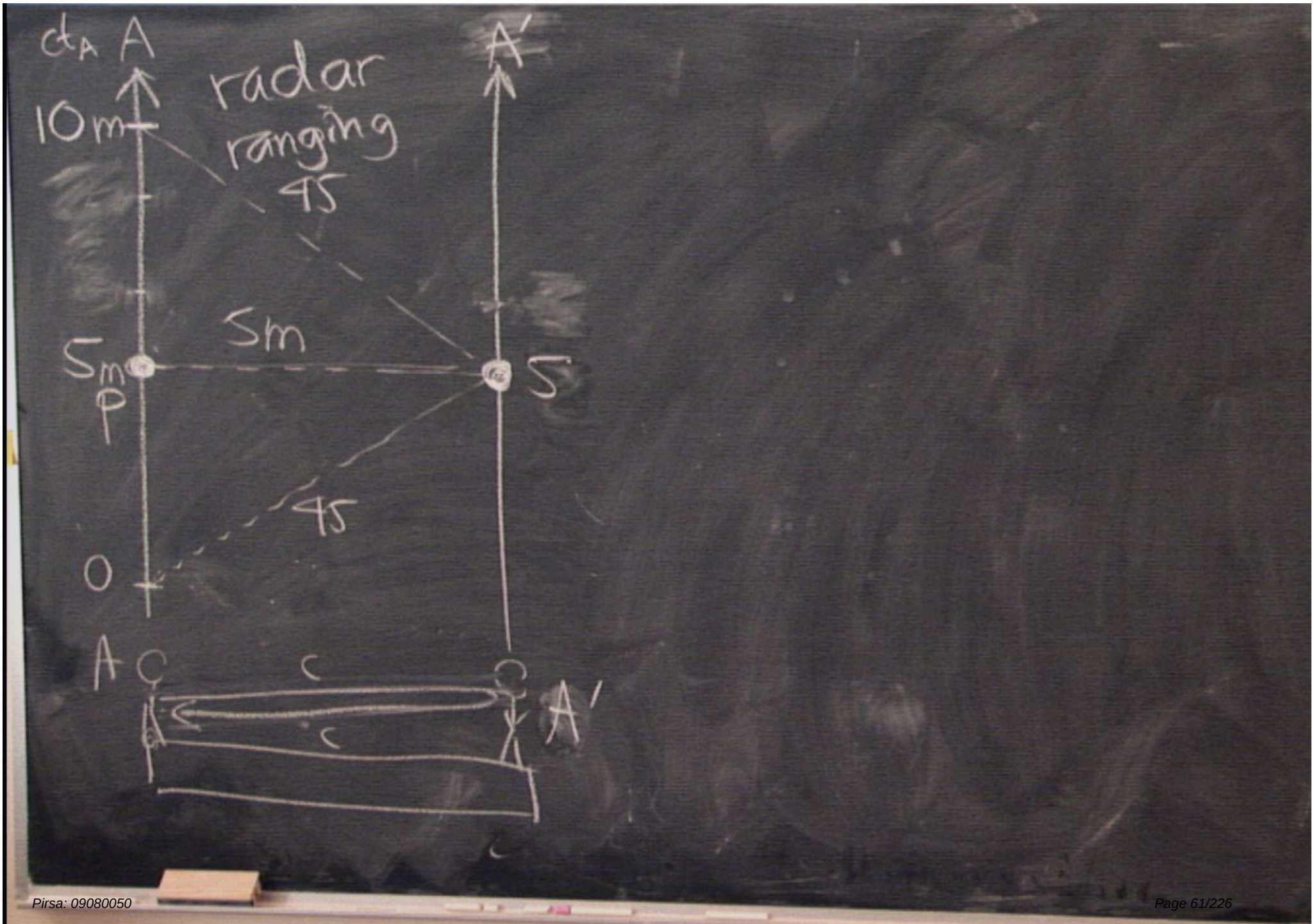

A
A'
10
45
5
P
45
0
A
C
A'

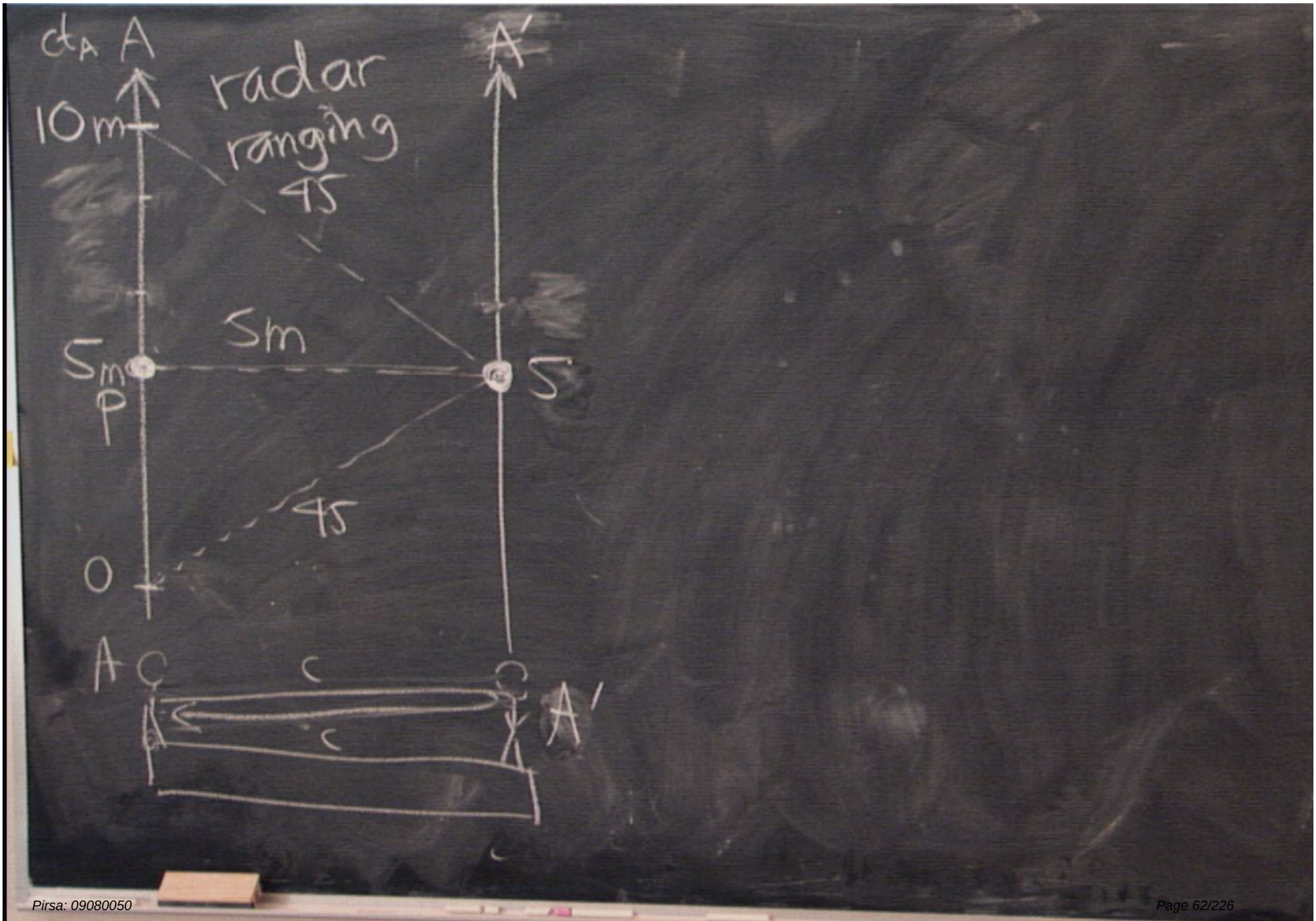

A
A'
10
45
5
P
7
45
0
A
C
A'

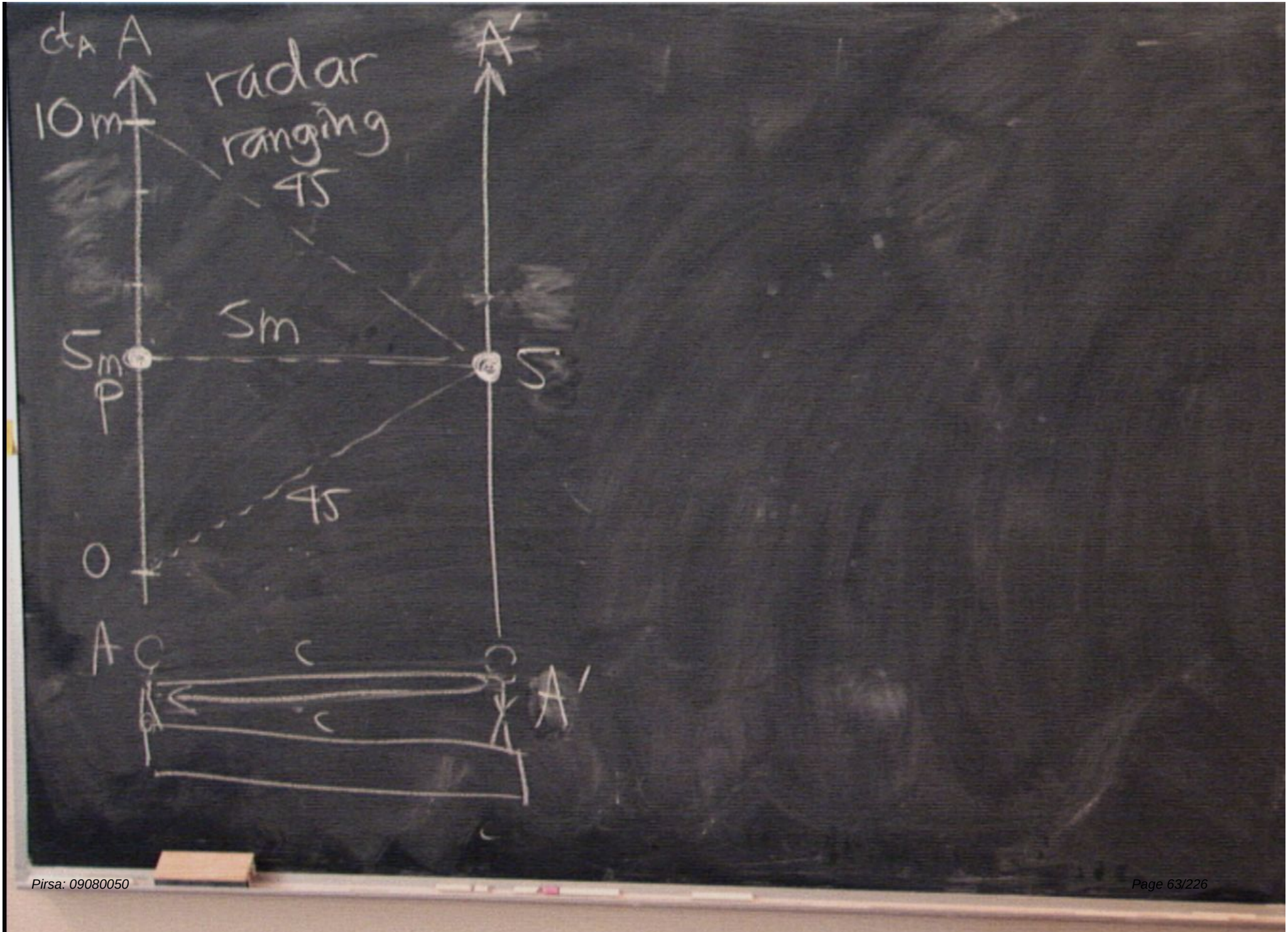

A
A'
10
45
S
S
P
45
0
A
C
C
C
A'


A
A'
10
45
S
S'
P
45
0
A
C
A'

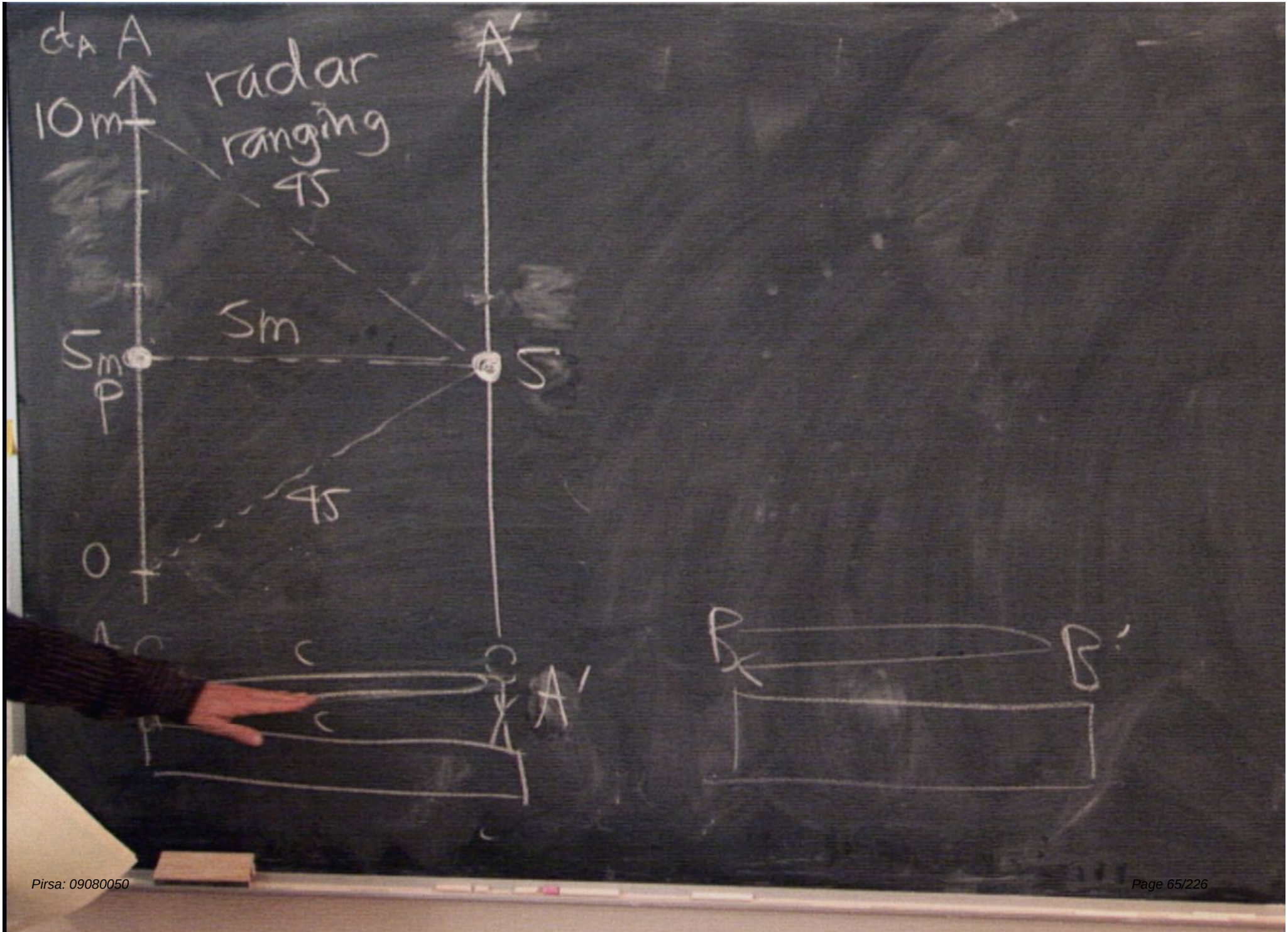

d_A A
A'
10 m
45
5m
5m
P
S
45
0
A
C
C
C
A'

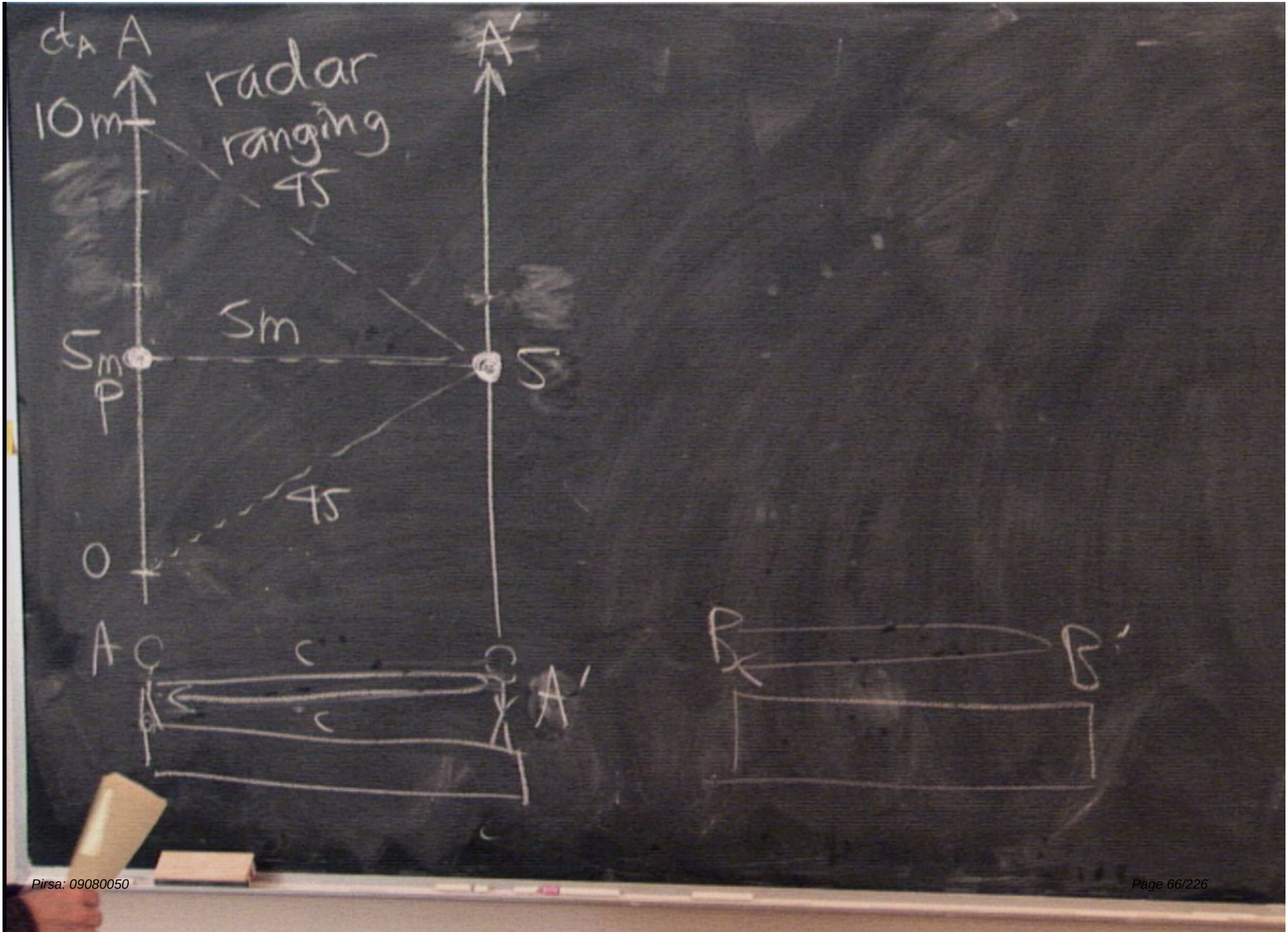

dt_A A
A'
10 m
radar
ranging
45
5m
5m
P
S
45
0
A
C
C
C
A'

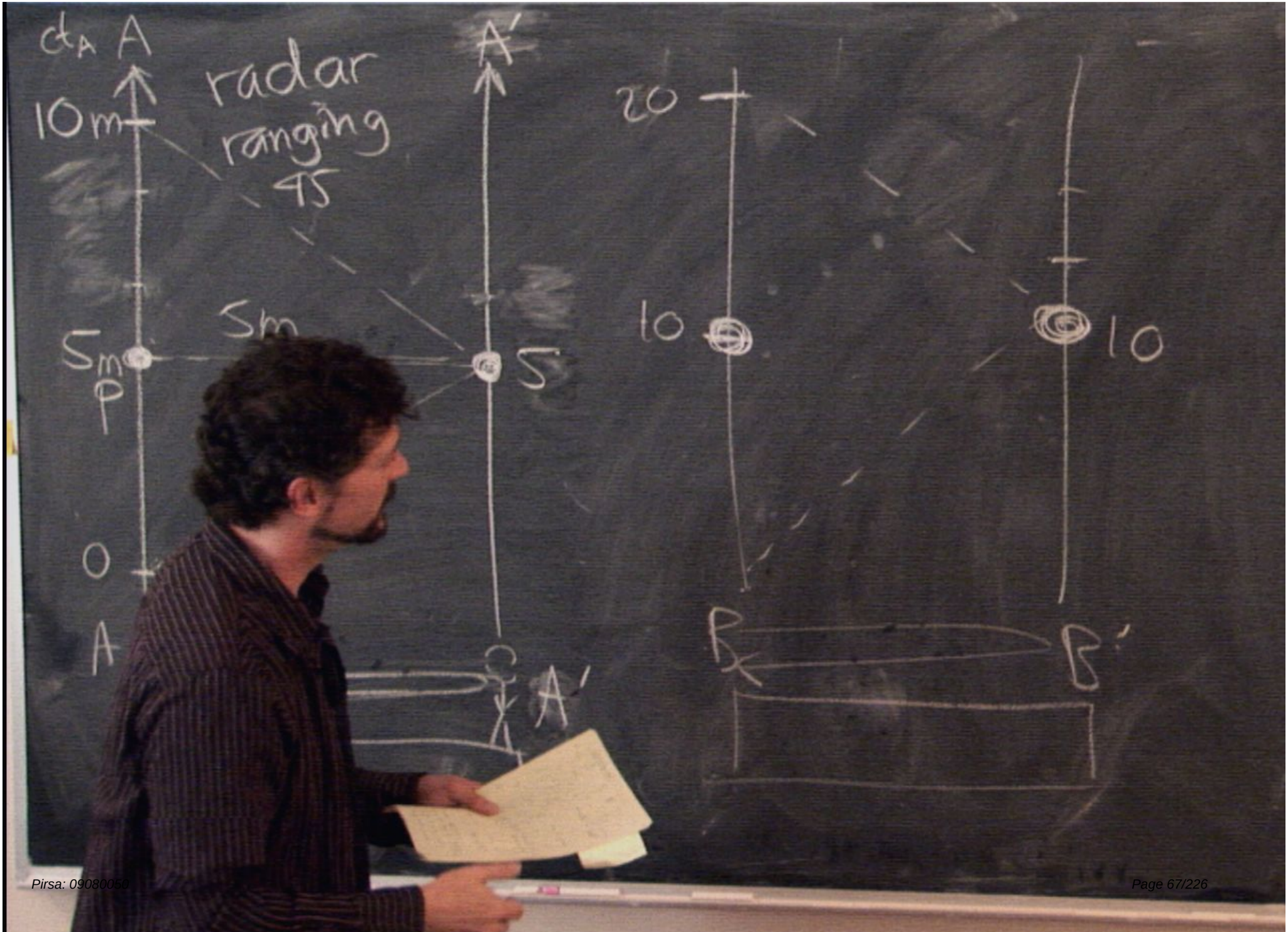

ct_A A
A'
10 m
radar
ranging
45
5m
5m
P
S
45
0
A
C
C
A'

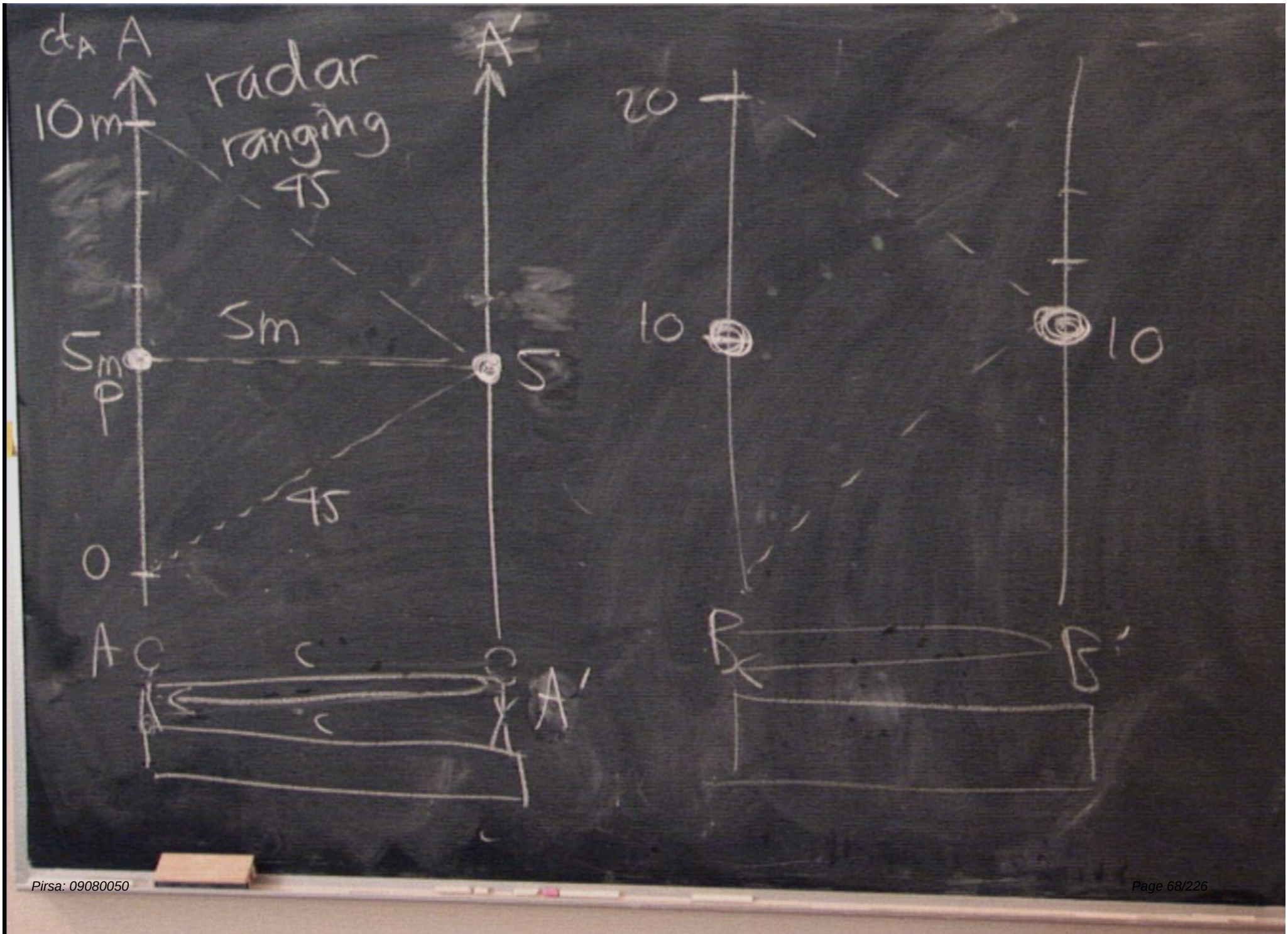

dt_A A
A'
10 m
radar
ranging
45
5m
5m
P
S
45
0
A
C
C
C
A'

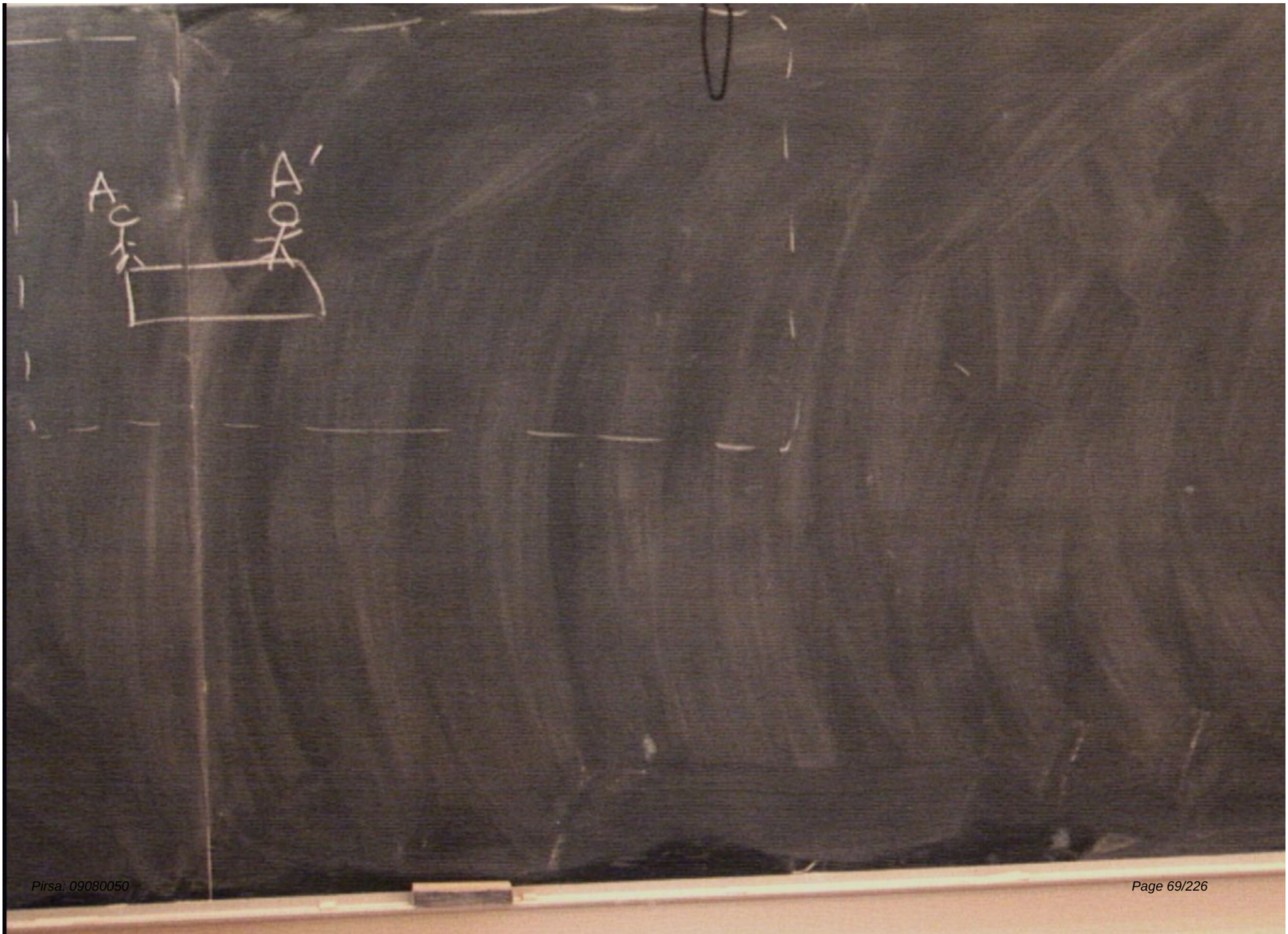

ct_A A
10m
radar
ranging
45
A'
5m
5m
S
45
0
A'
B
B'

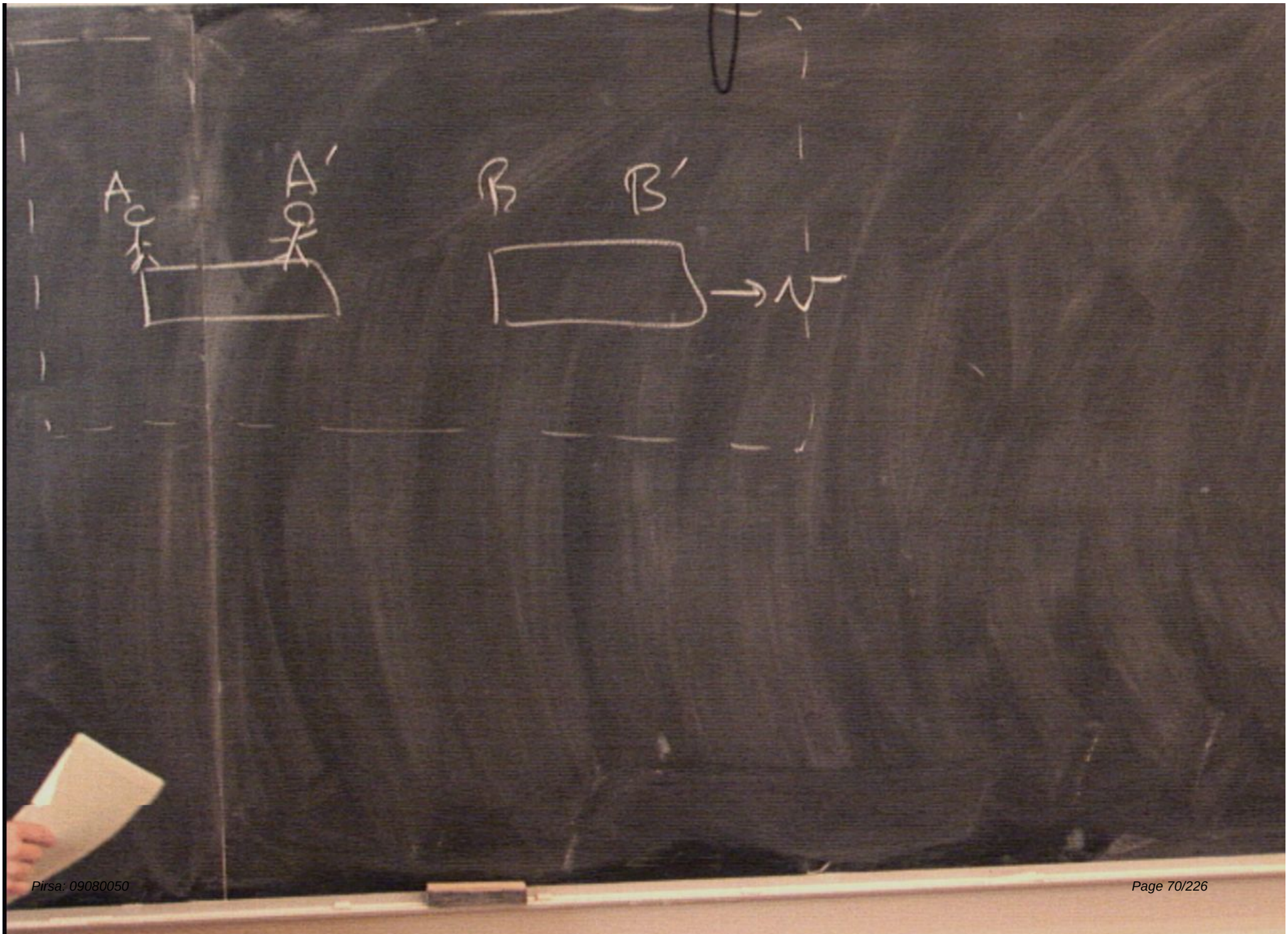

ct_A A
A'
10 m
radar
ranging
45
5m
5m
P
S
45
0
A'
B
B'

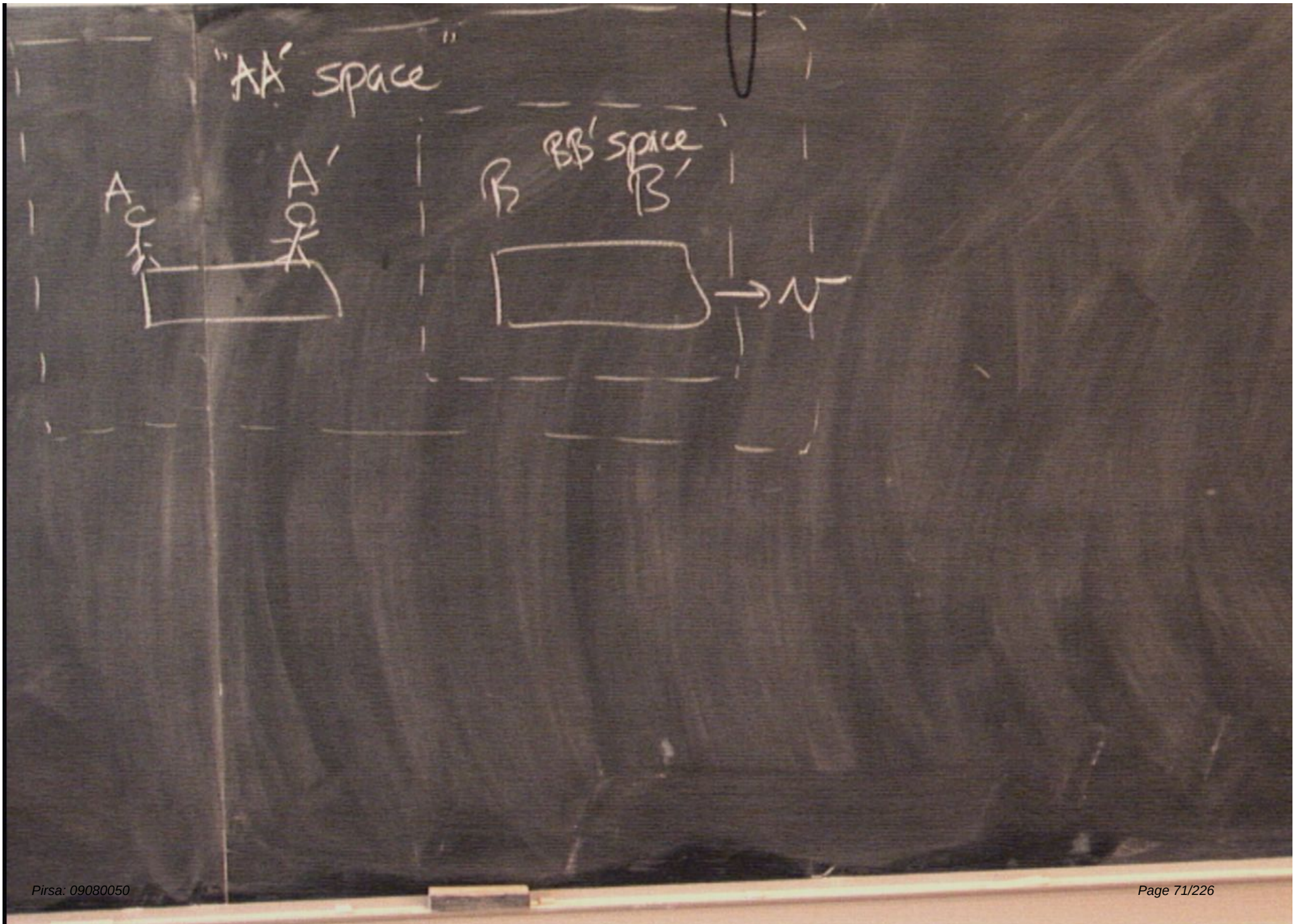

ct_A A
A'
10 m
radar
ranging
45
5m
S
P
S
45
0
A
C
C
A'
B
B'

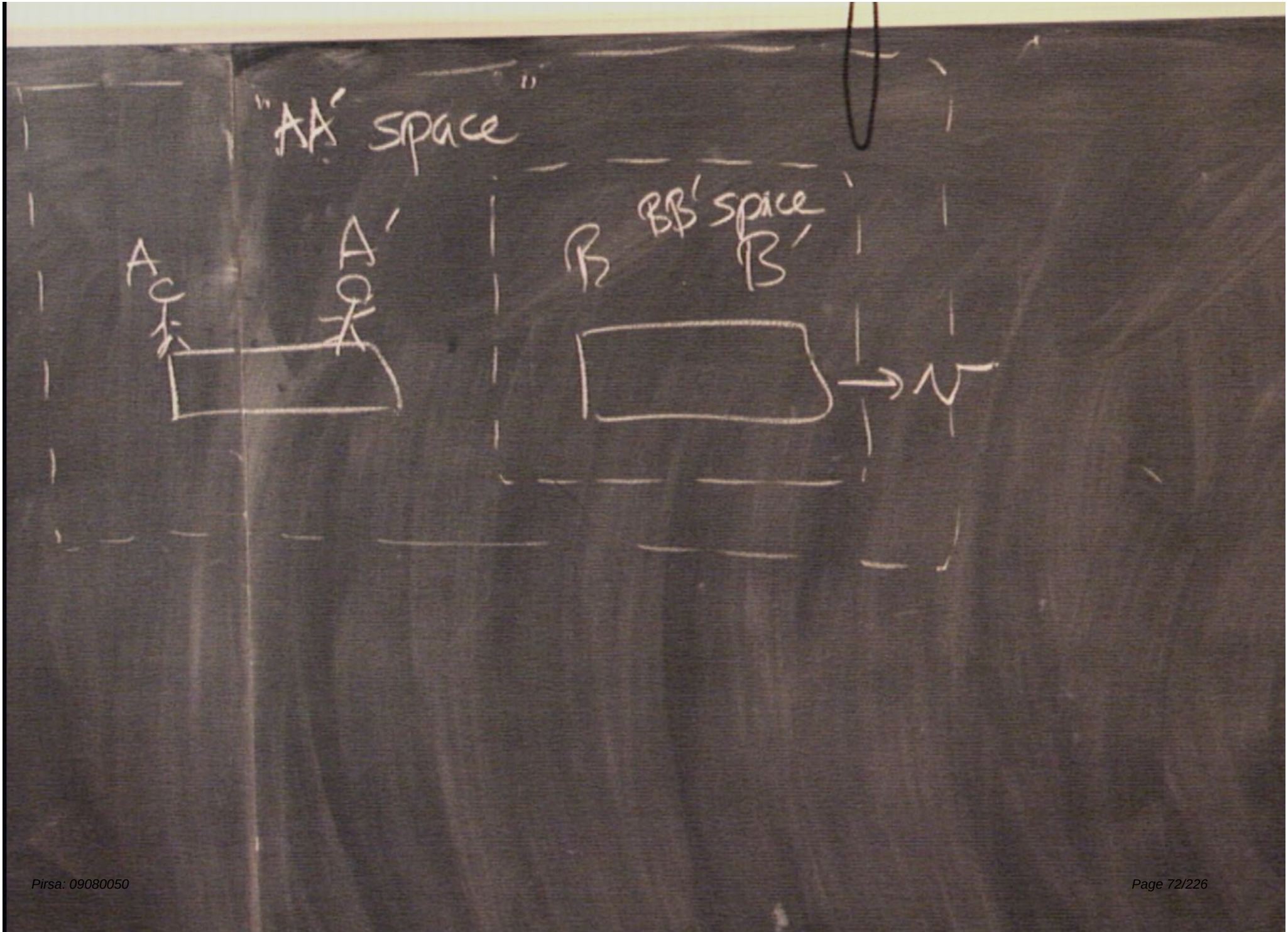

d_A A
10m
radar
ranging
45
A'
5m
5m
P
5
0
A
A'
20
10
10
B
B'

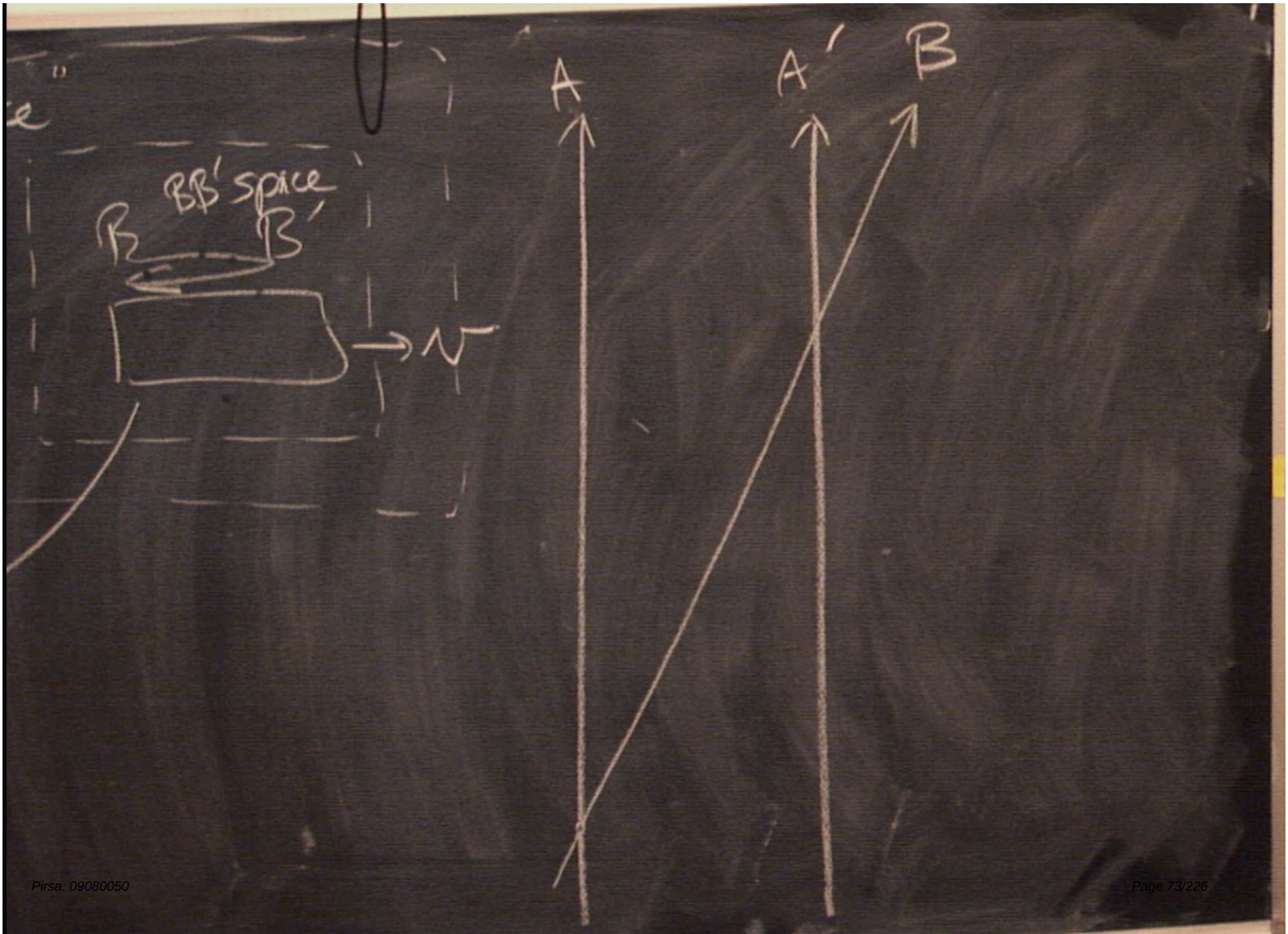

d_A A
A'
10m
radar
ranging
45
5m
5m
P
S
45
0
A
C
C'
A'
20
10
10
B
B'

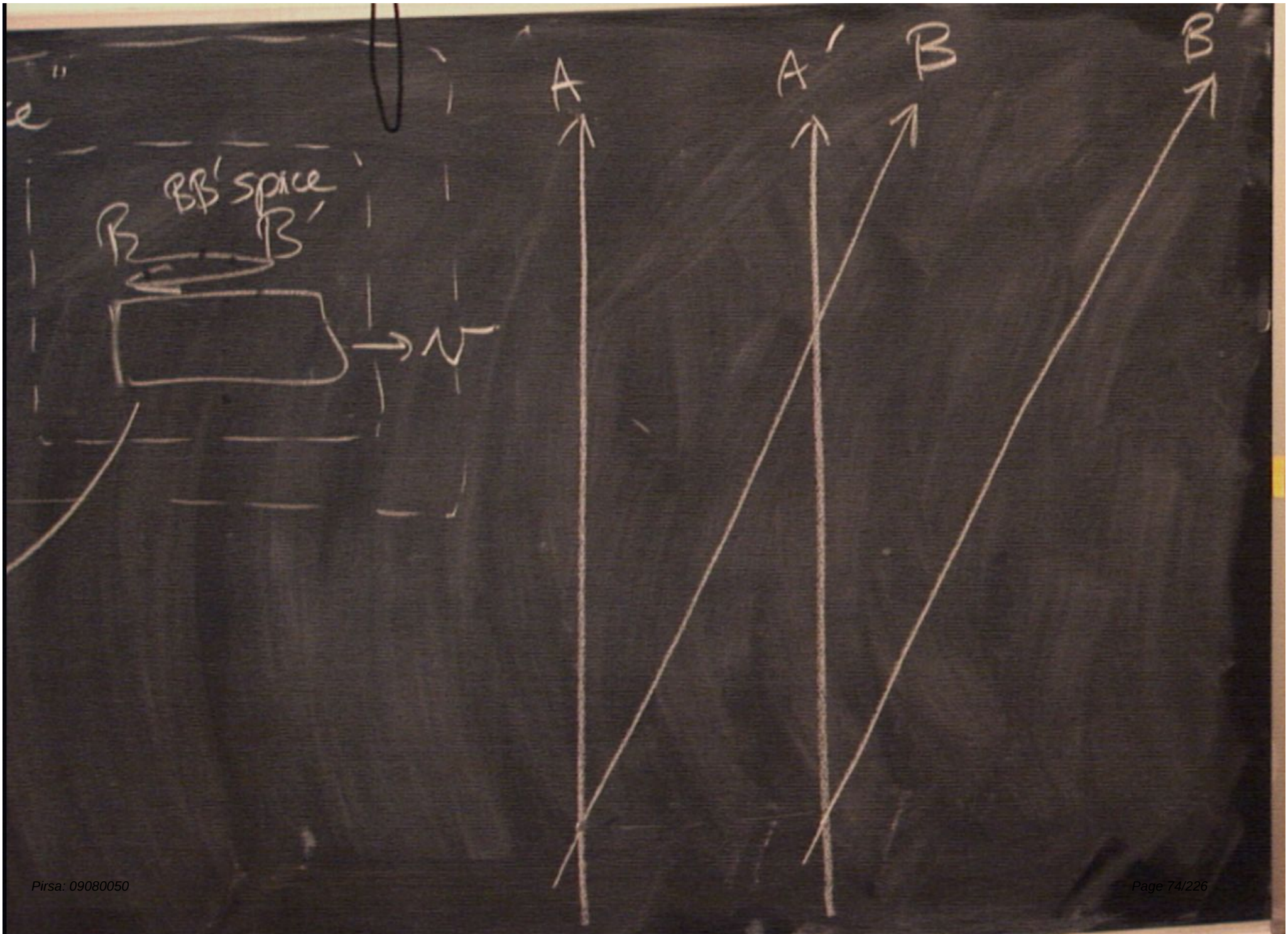

A
A'

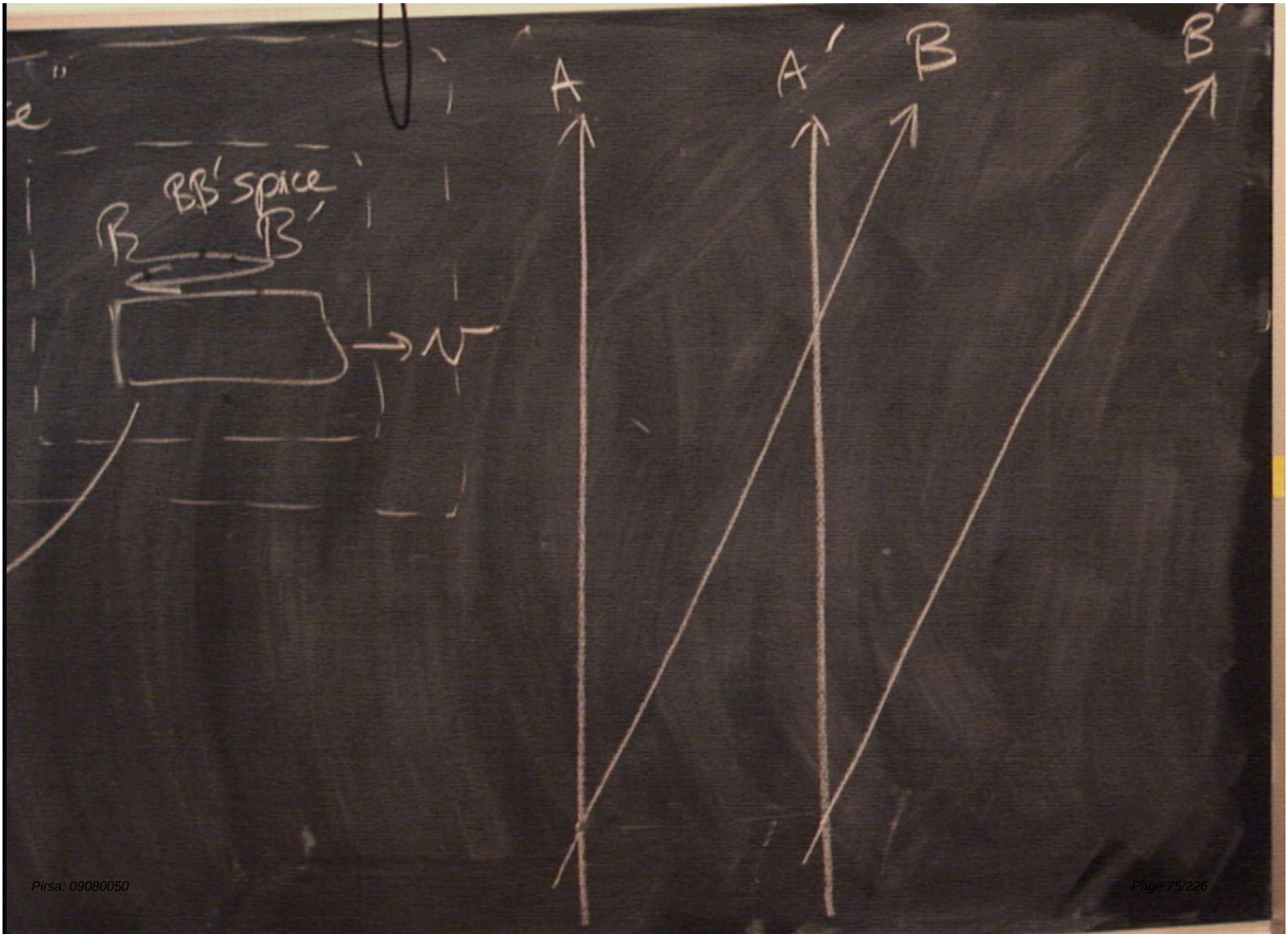

A
A′
B
B′

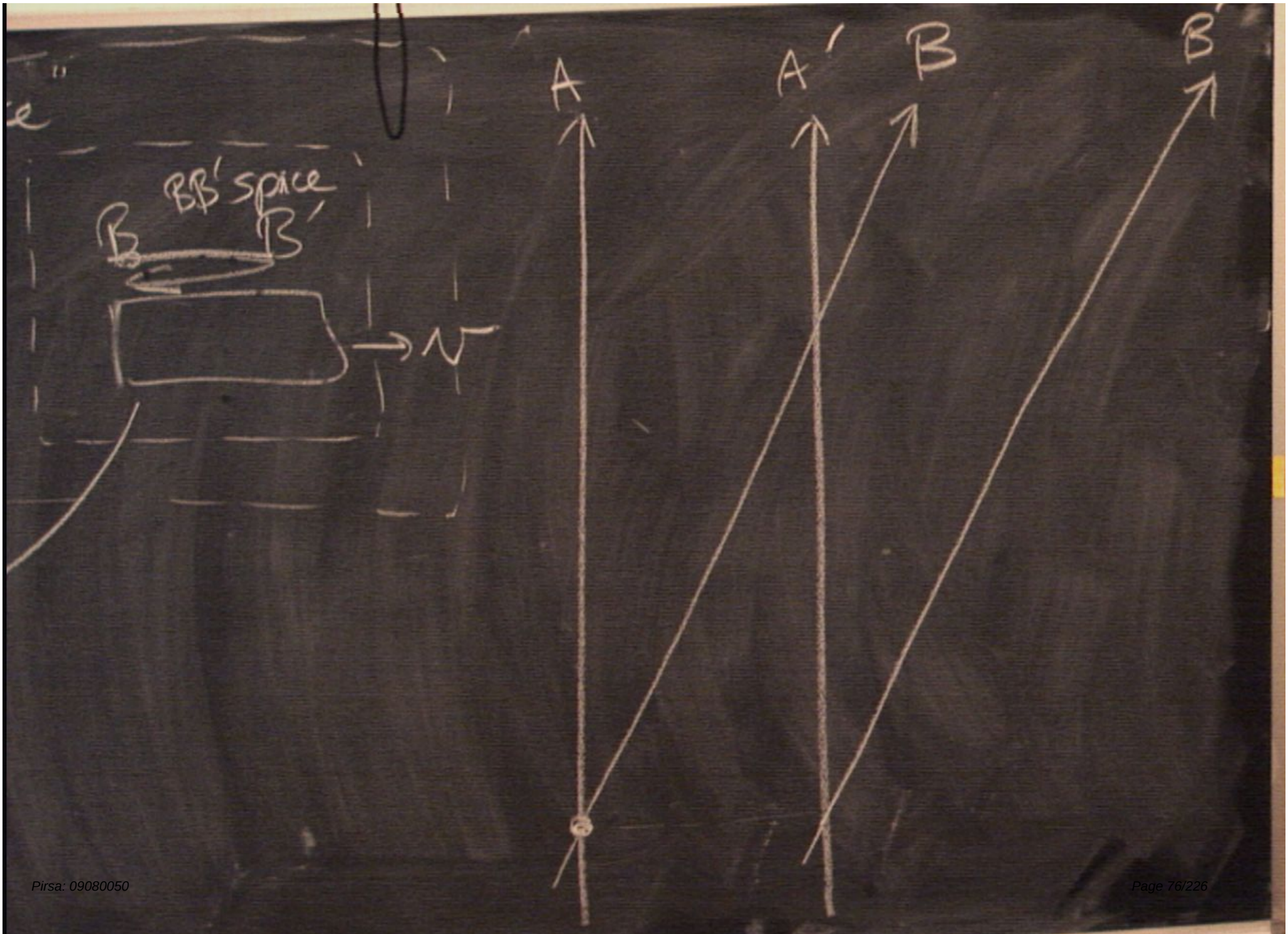

"AA' space"
A
A'
BB' space
B
B'
v

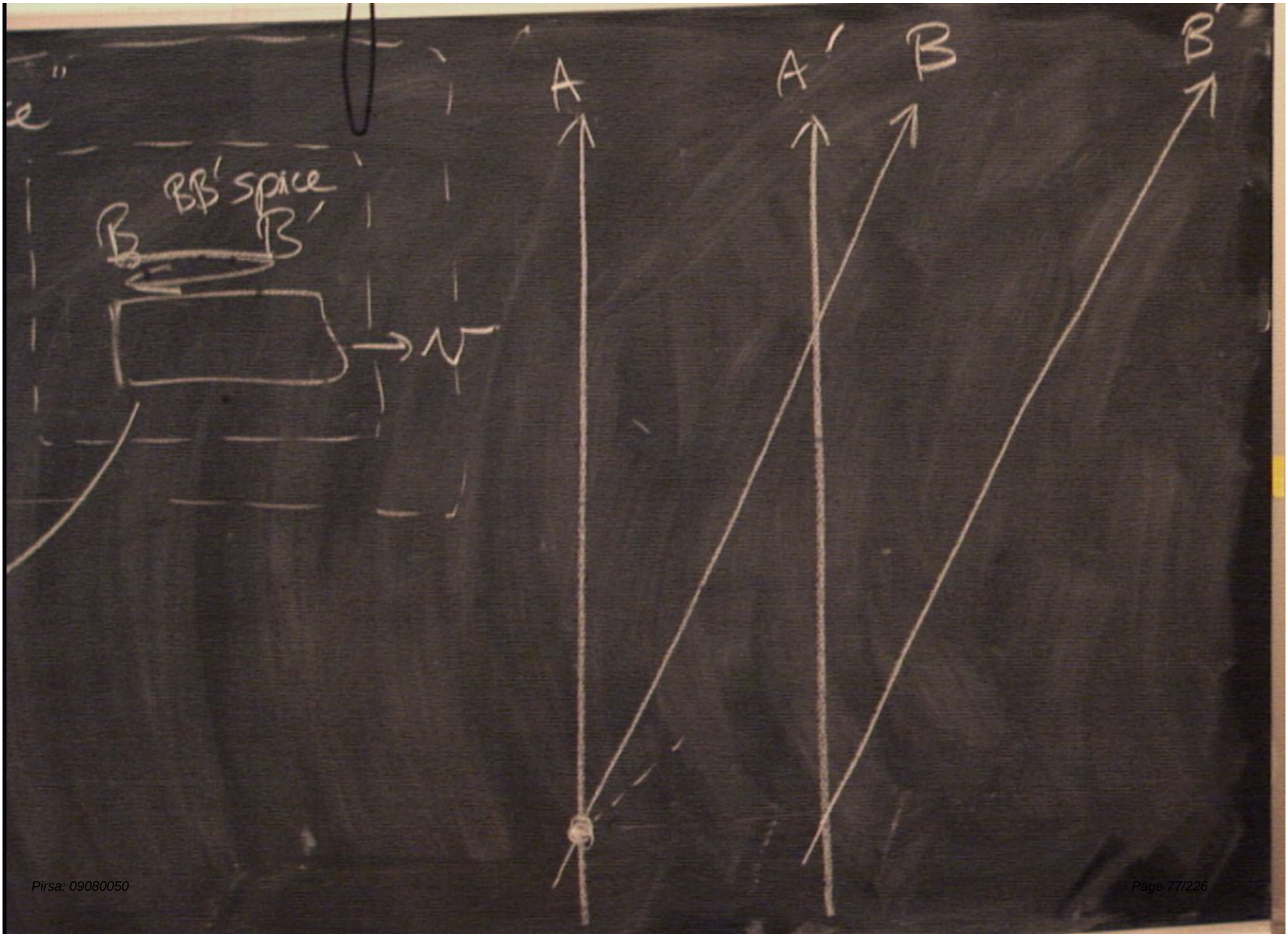

"AA' space"
A
A'
B
BB' space
B'

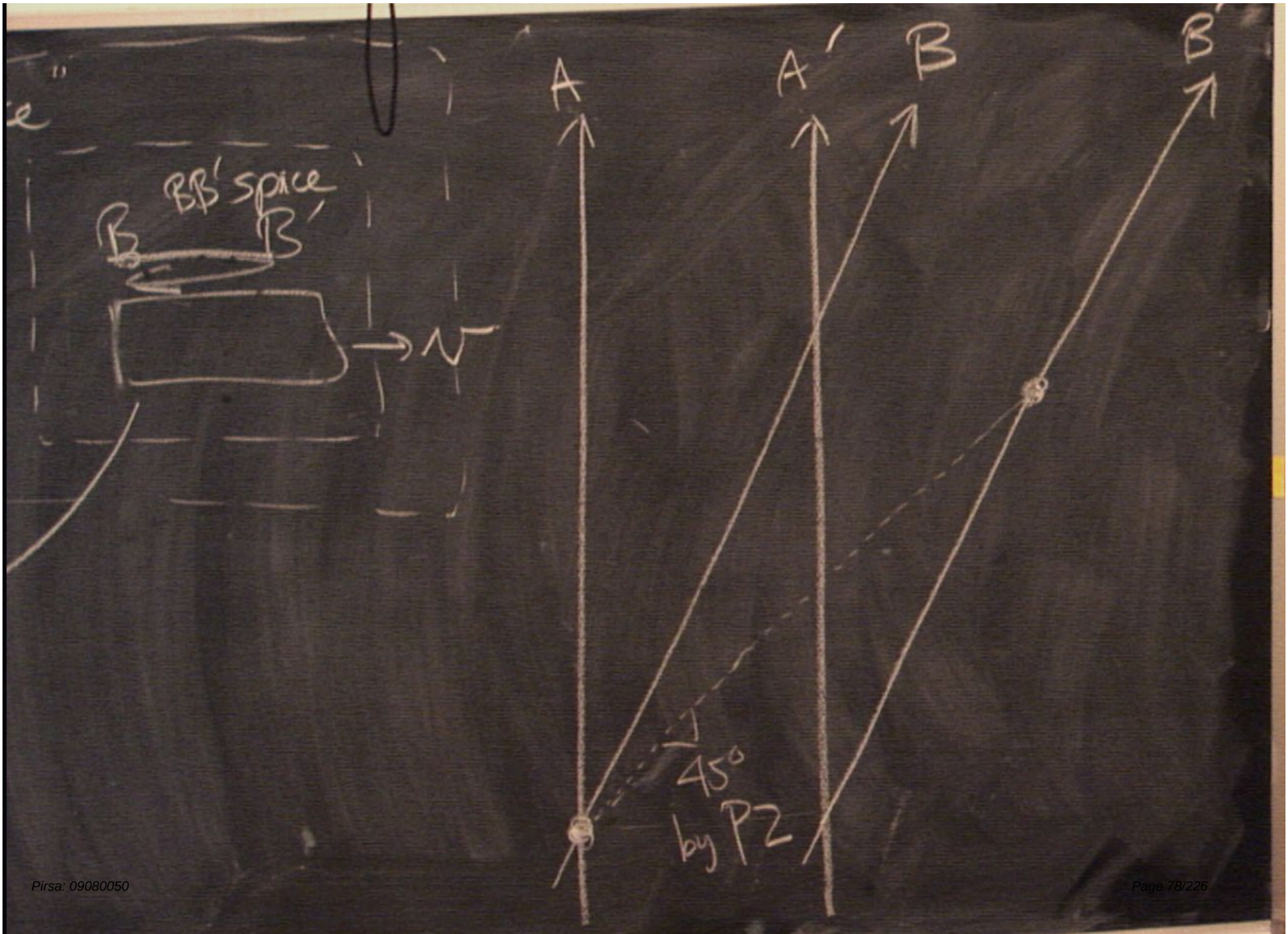

BB' space
B
B'
A
A'
B

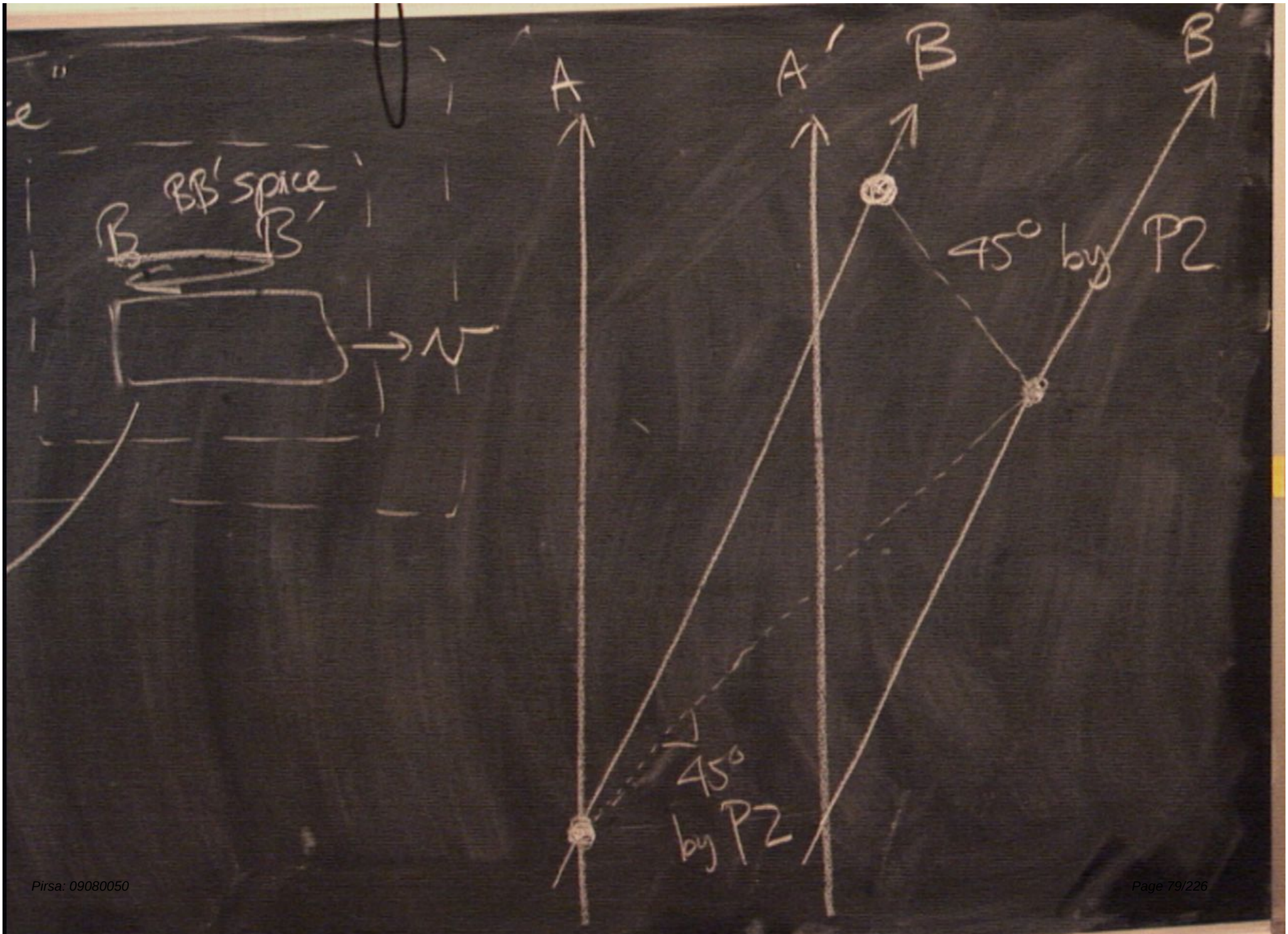

BB' space
B
B'
A
A'
B
B'

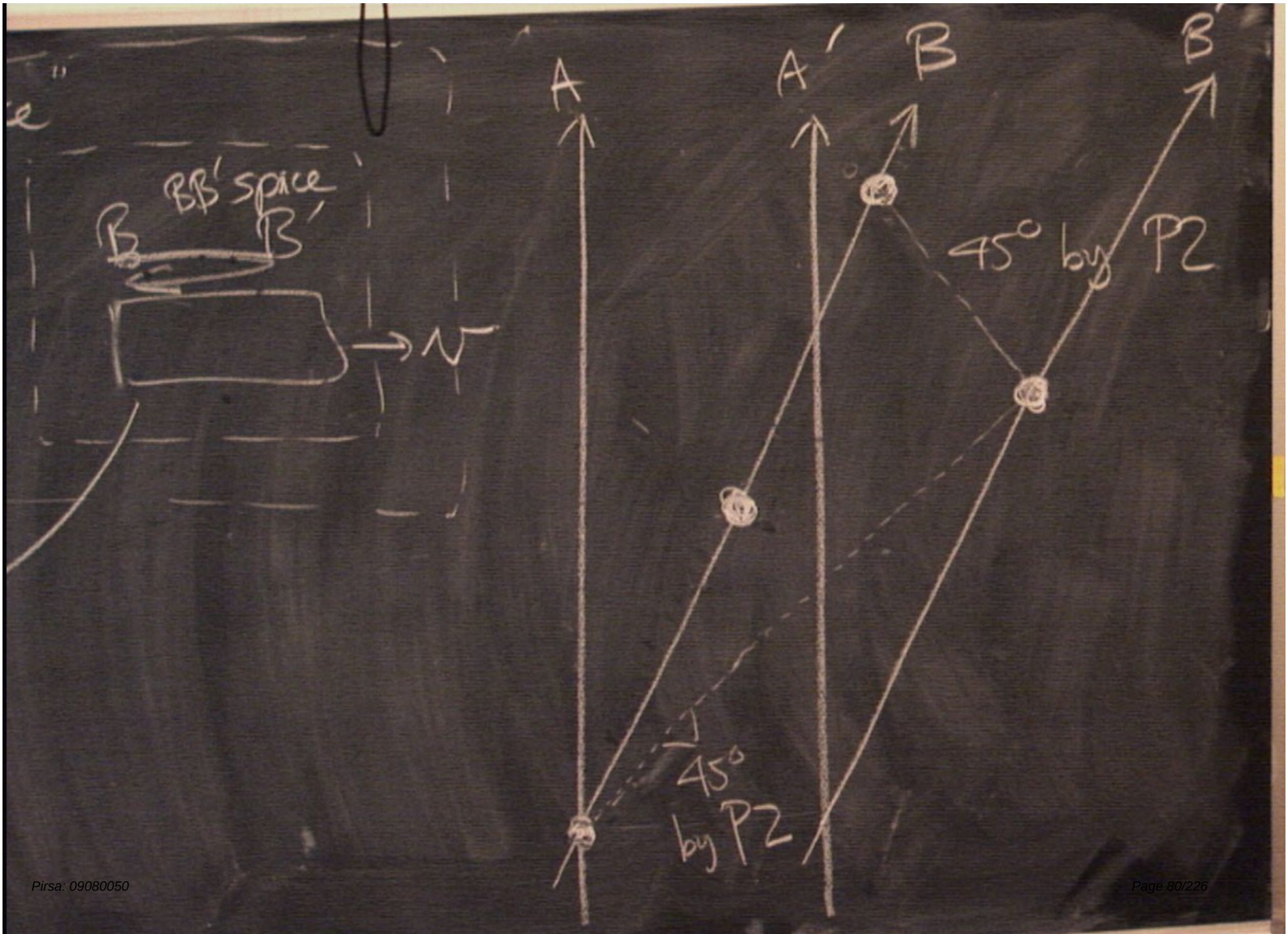

BB' space
B
B'
A
A'
B
B'

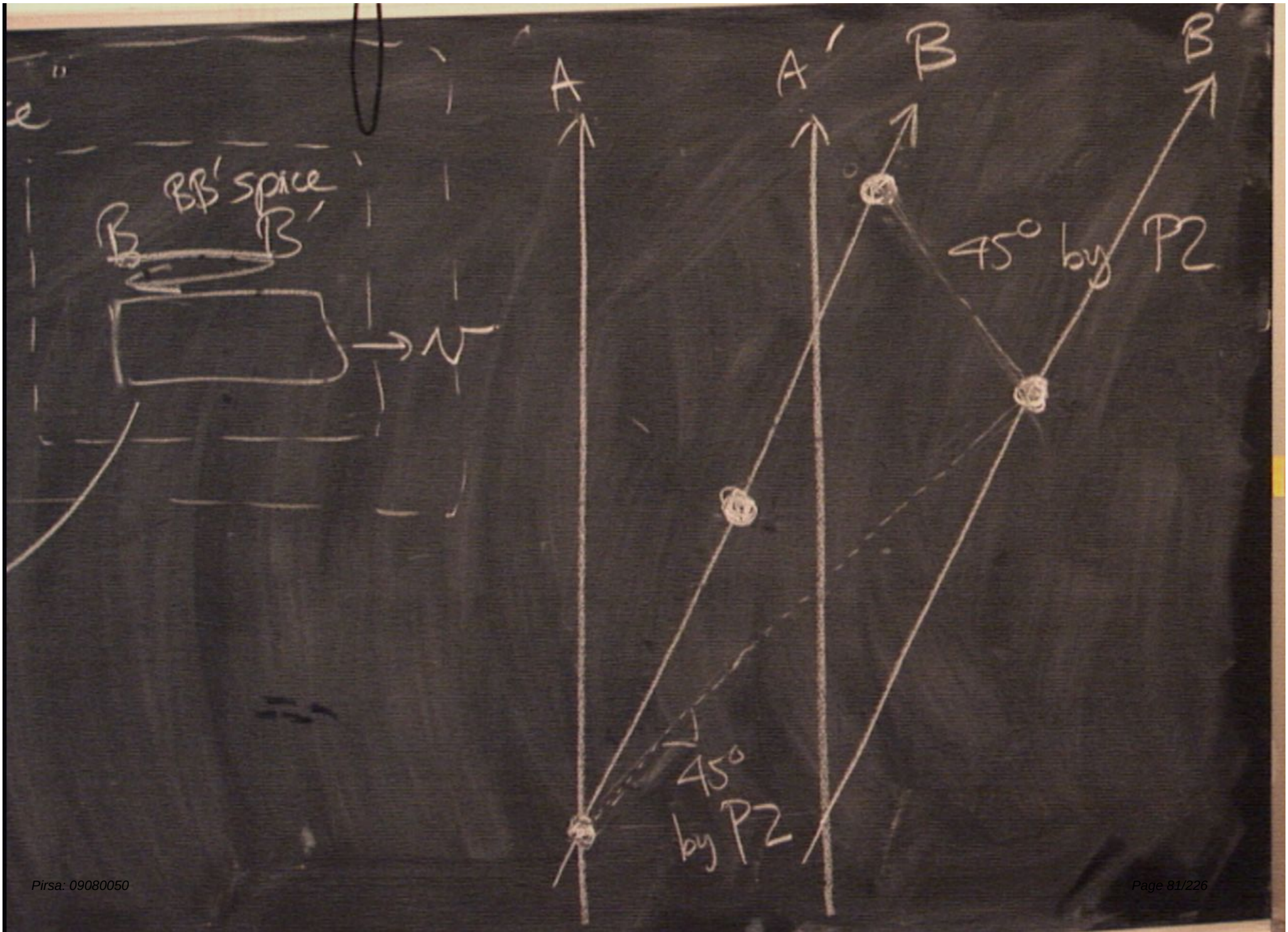

BB' space
B
B'
A
A'
B
B'

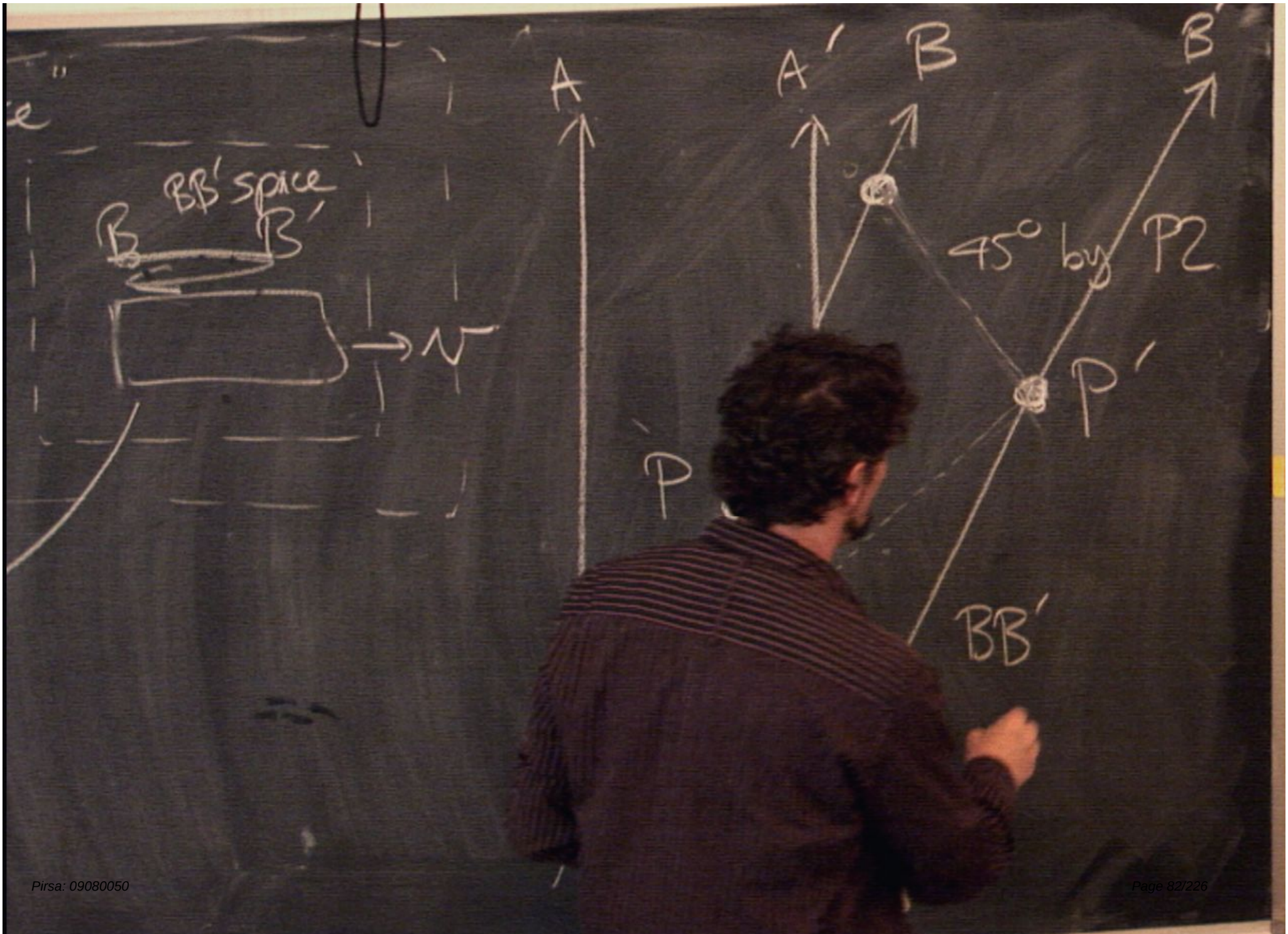

BB' space
B
B'
A
A'
B
B'

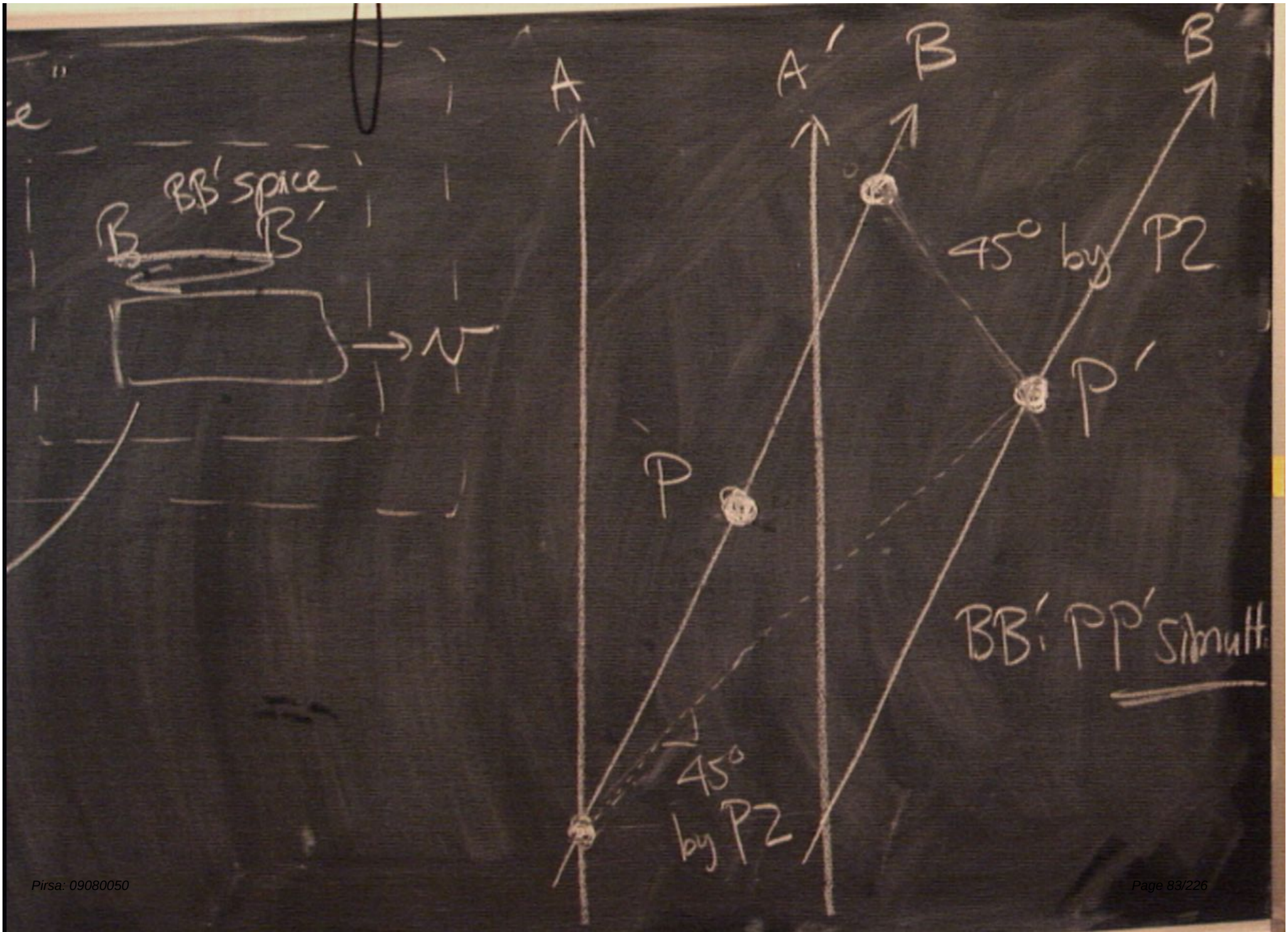

BB' space
B
B'
A
A'
B
B'
45°
by P2

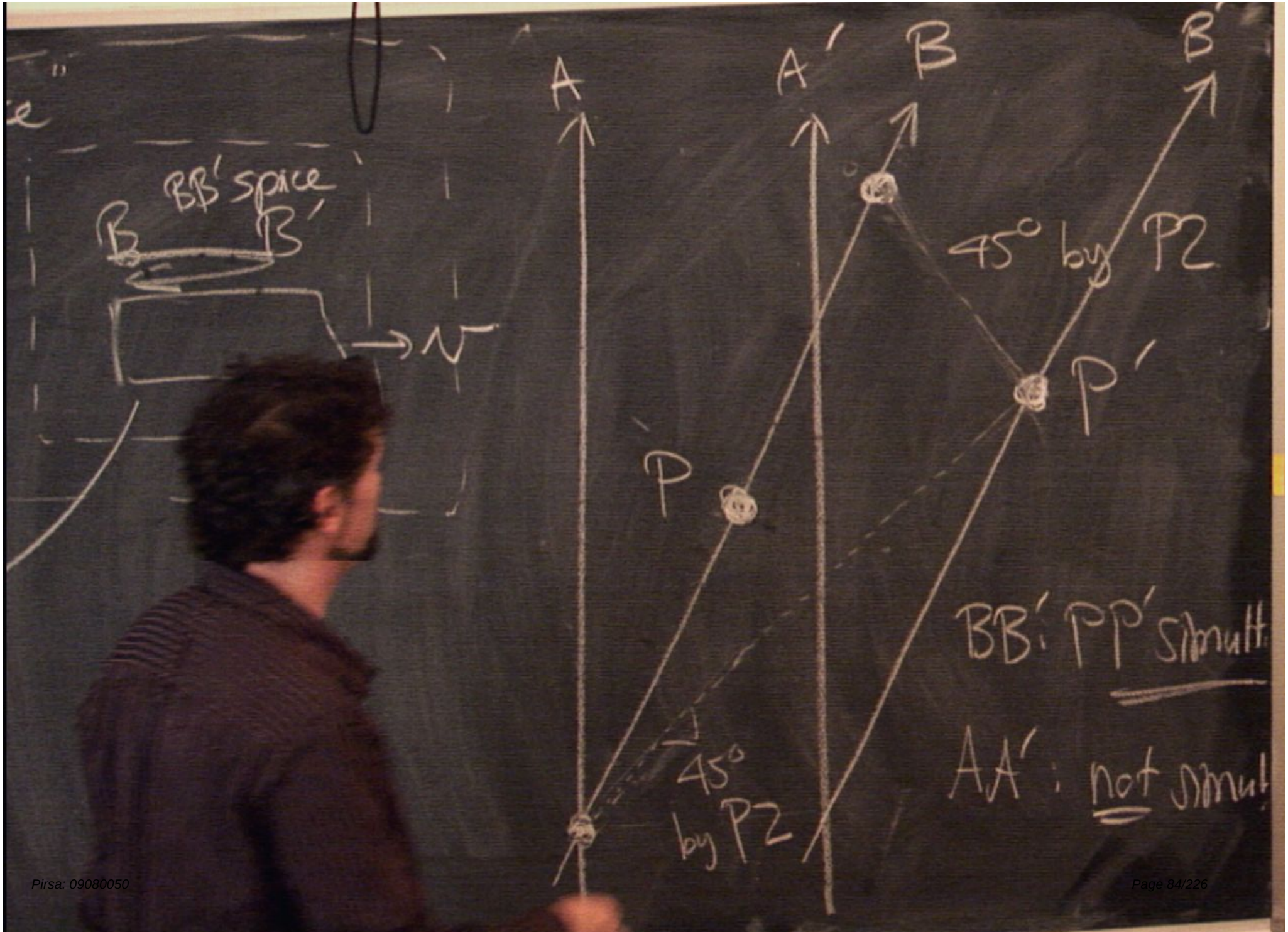

BB' space
B
B'
A
A'
B
B'
45° by P2
45° by P2

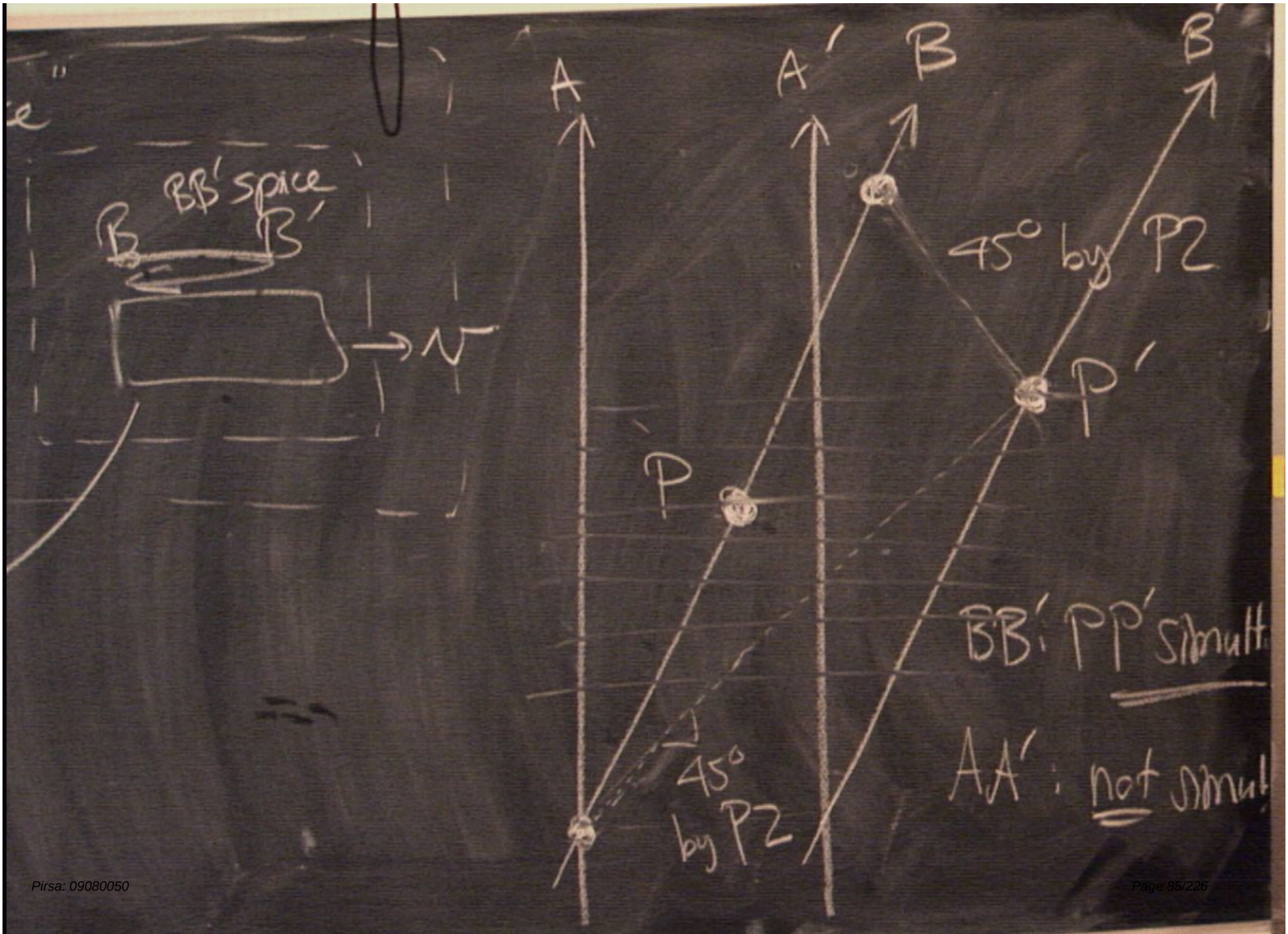

BB' space
B
B'
A
A'
B
B'
45° by P2
45°
by P2

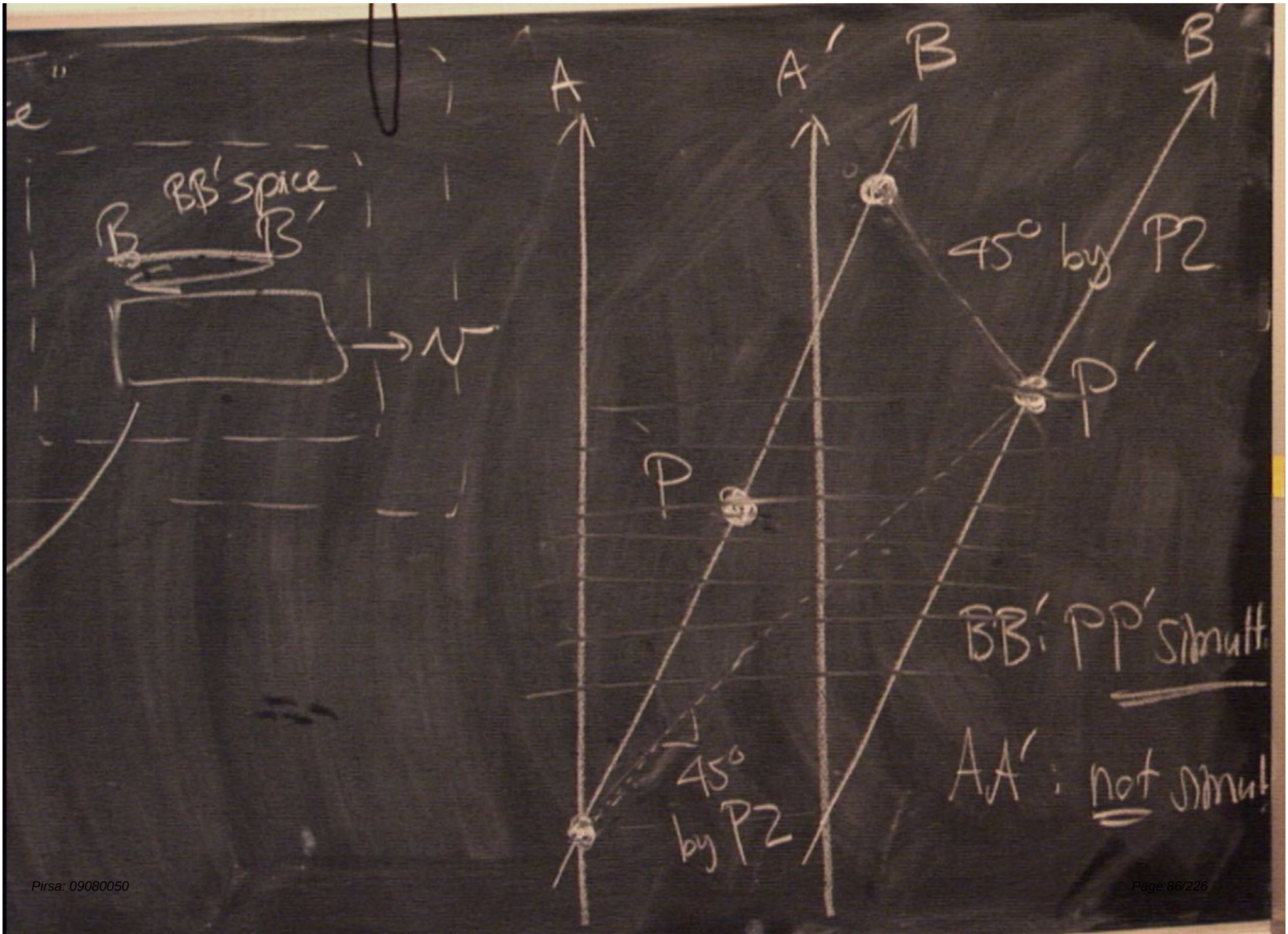

BB' space
B
B'
A
A'
B
B'
45° by P2
45° by P2

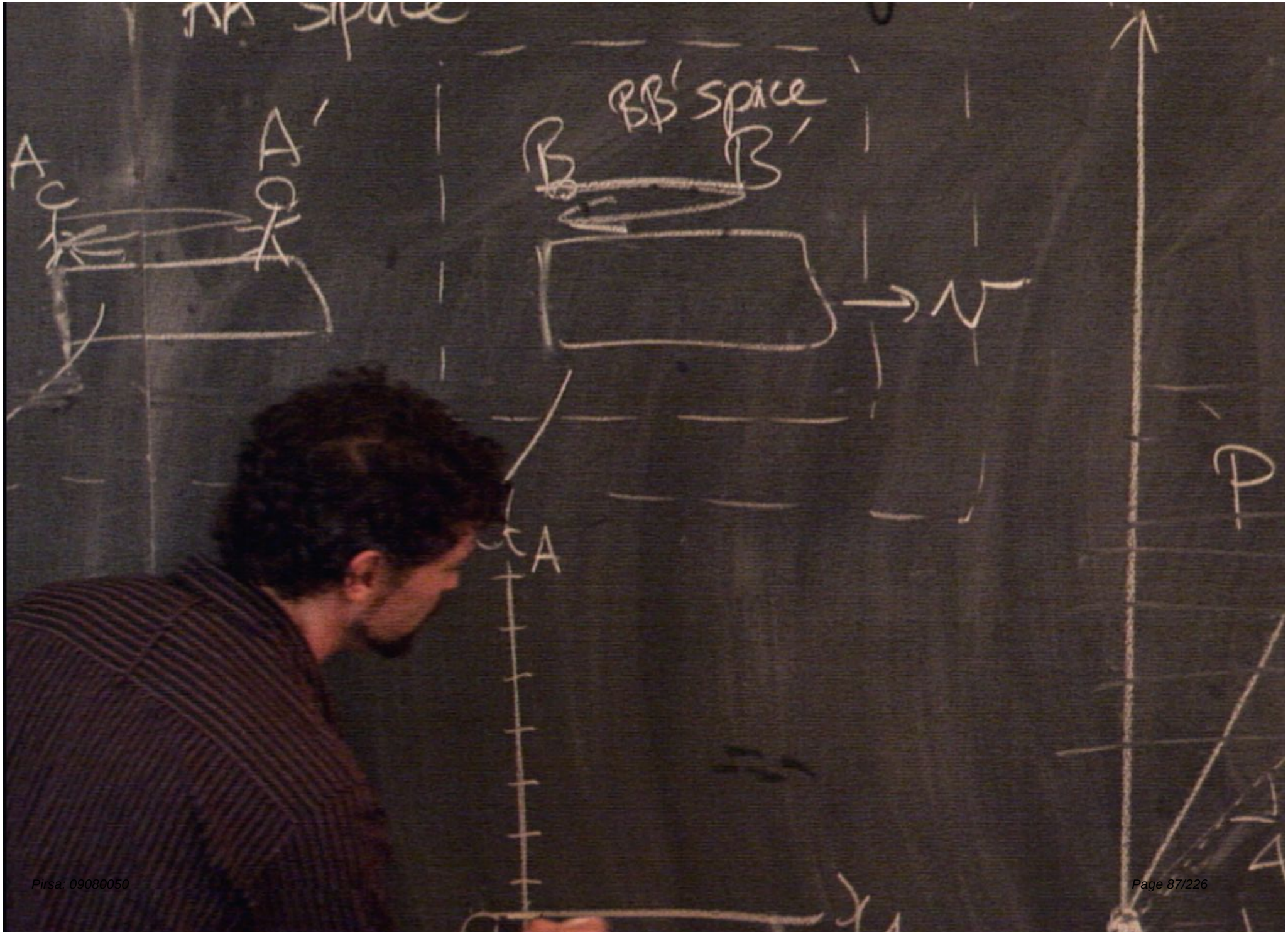

BB' space
B
B'
A
A'
B
B'
45° by
P2
P'
P
BB'

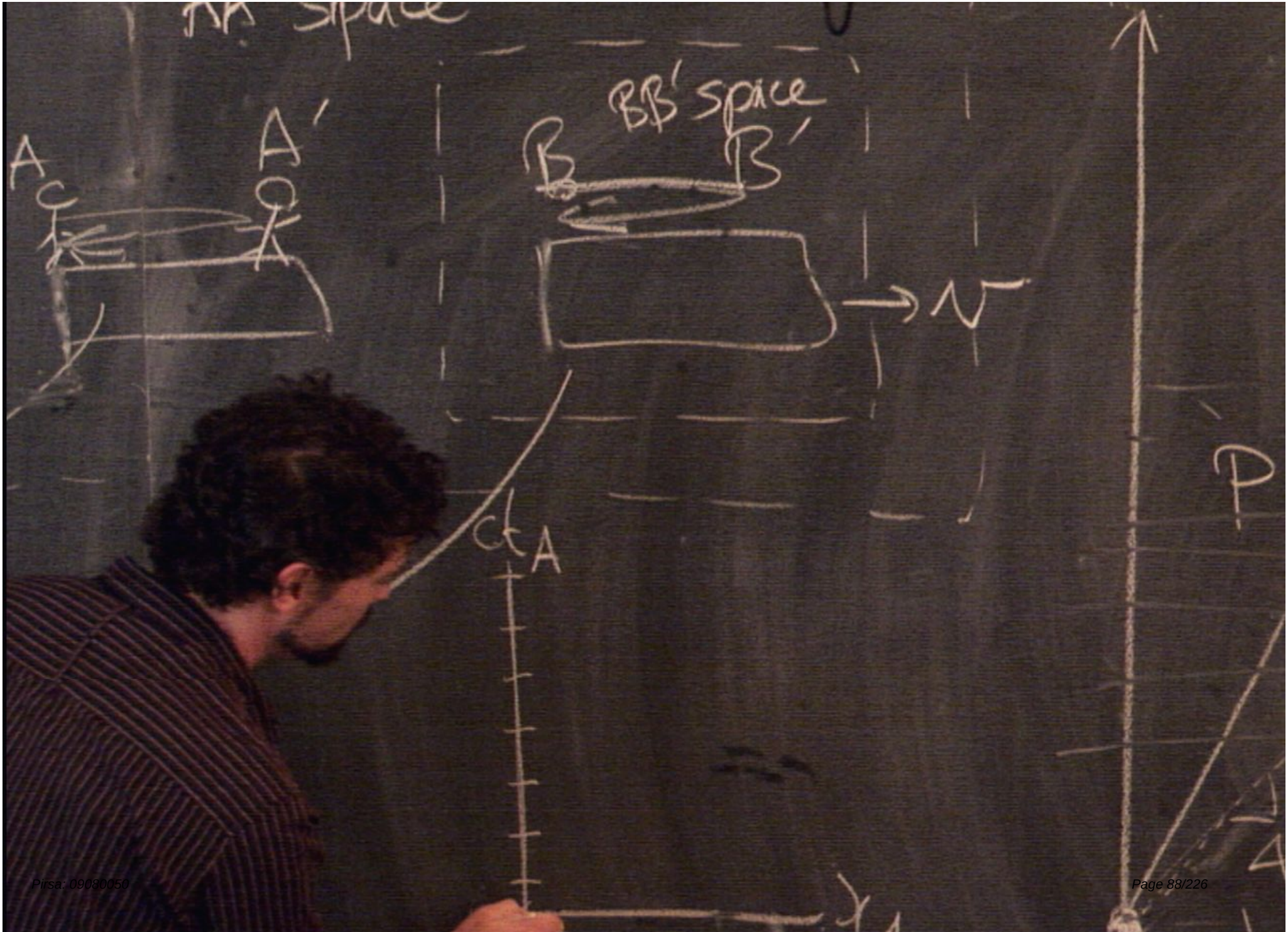

BB' space
B
B'
A
A'
B
B'
45° by P2
P'
P
BB' PP' simult.
45°
by P2

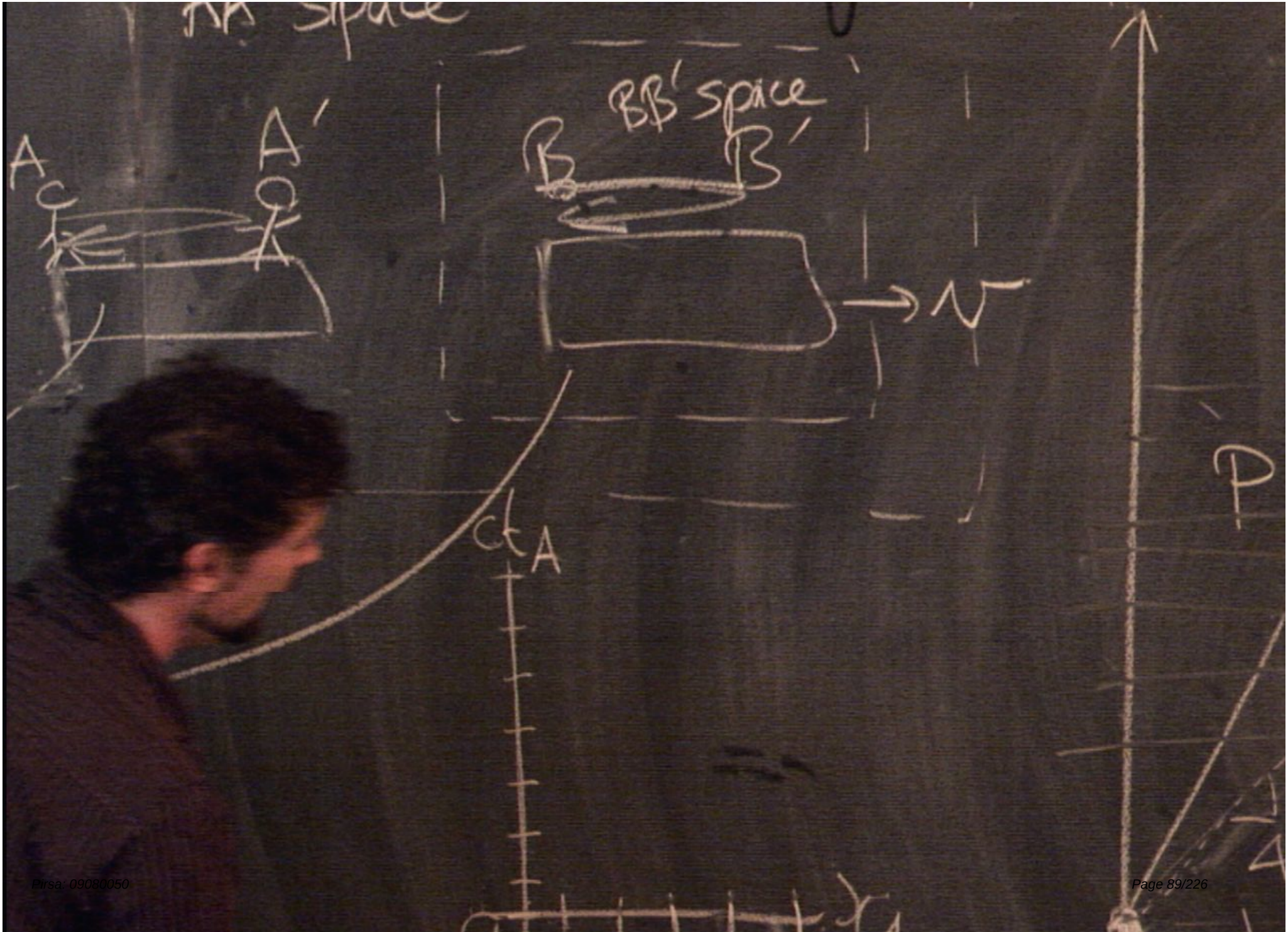

BB' space
B
B'
A
A'
B
B'
45° by P2
P
P'
BB': PP' simult.
AA': not simul
45° by P2

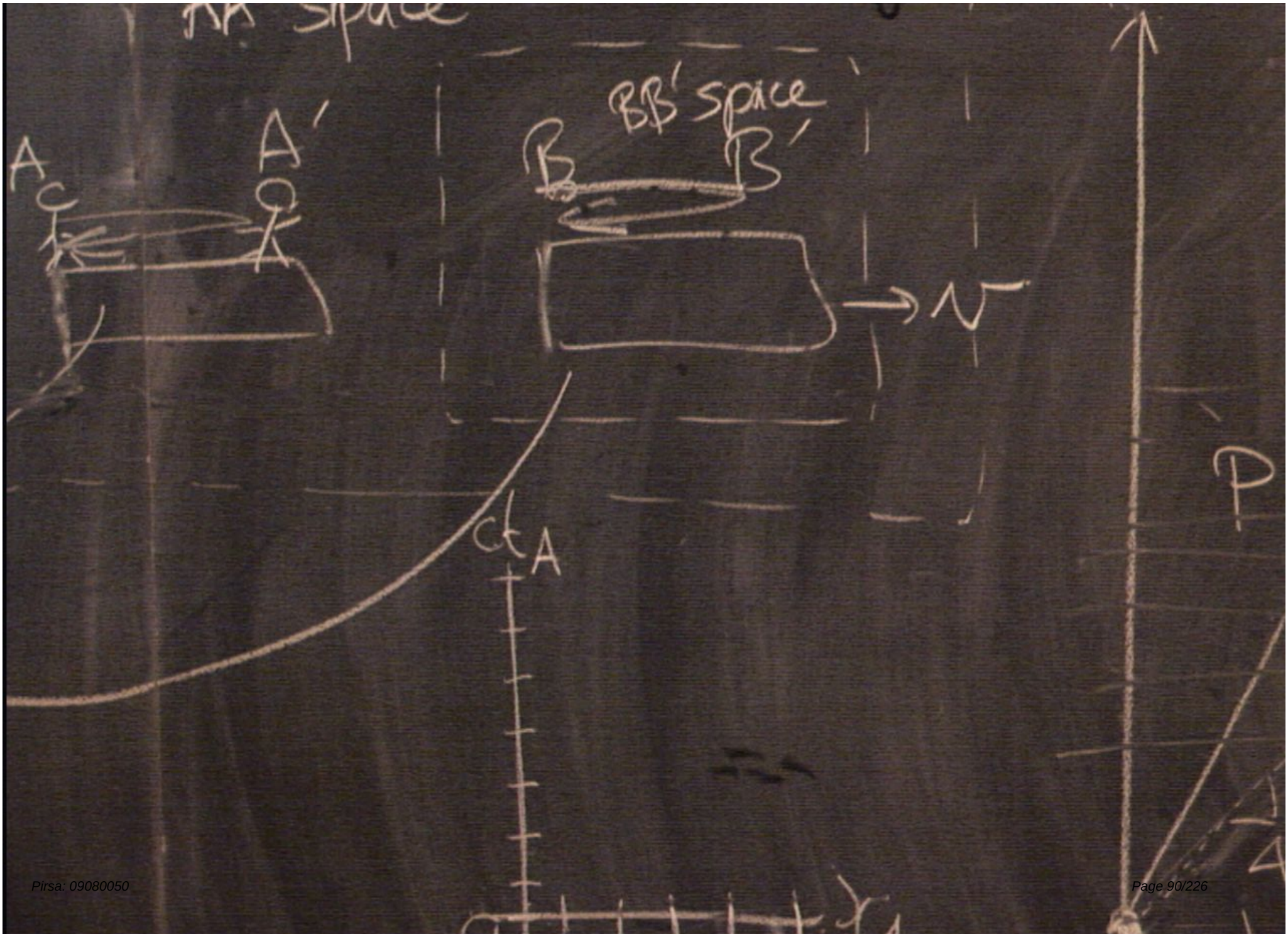

BB' space
B
B'
A
A'
B
B'
45° by P2
P
P'
BB': PP' simult.
AA': not simul
45° by P2

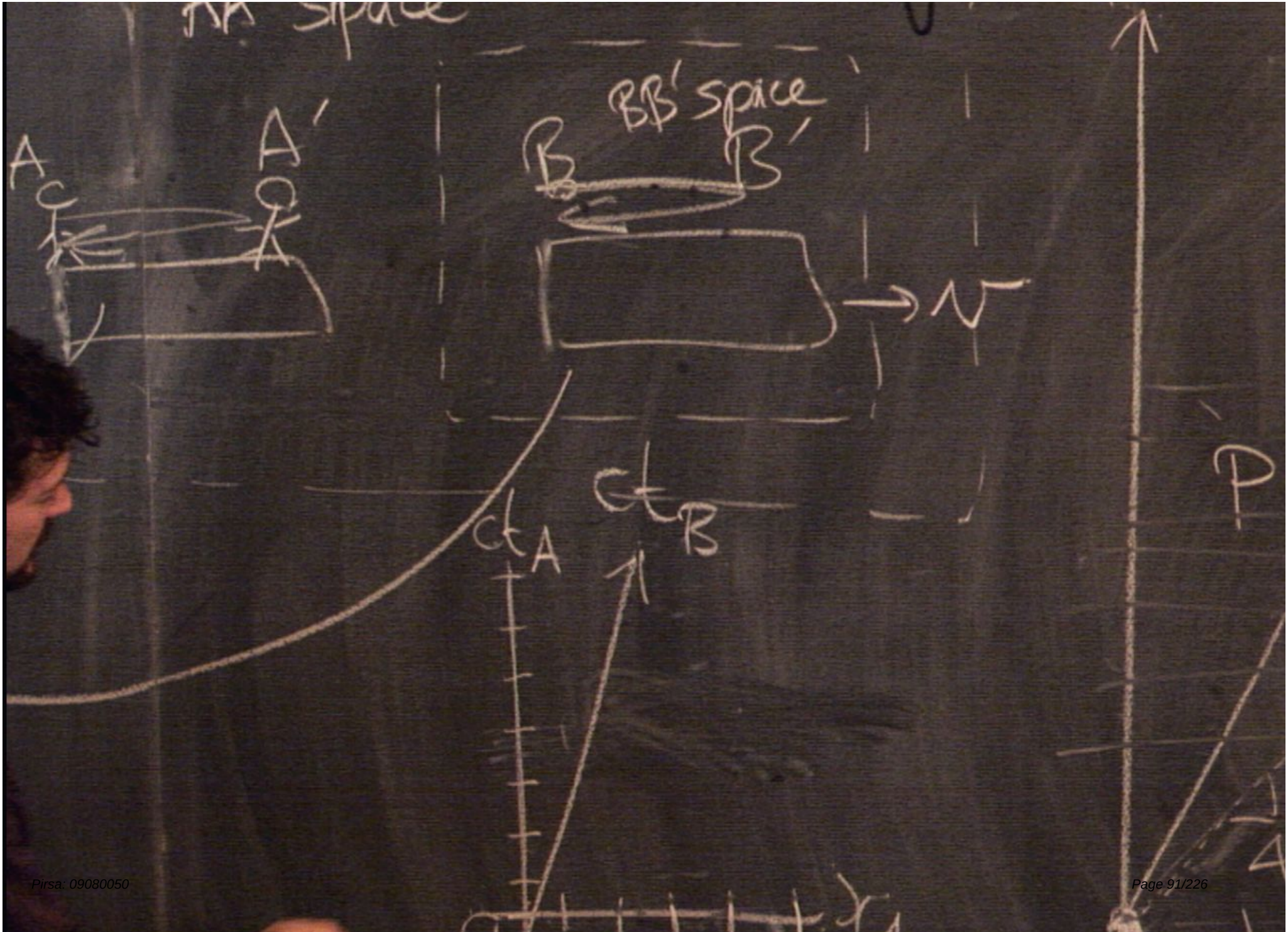

BB' space
B
B'
A
A'
B
B'
45° by P2
P'
P
BB': PP' simult.
AA': not simul
45°
by P2

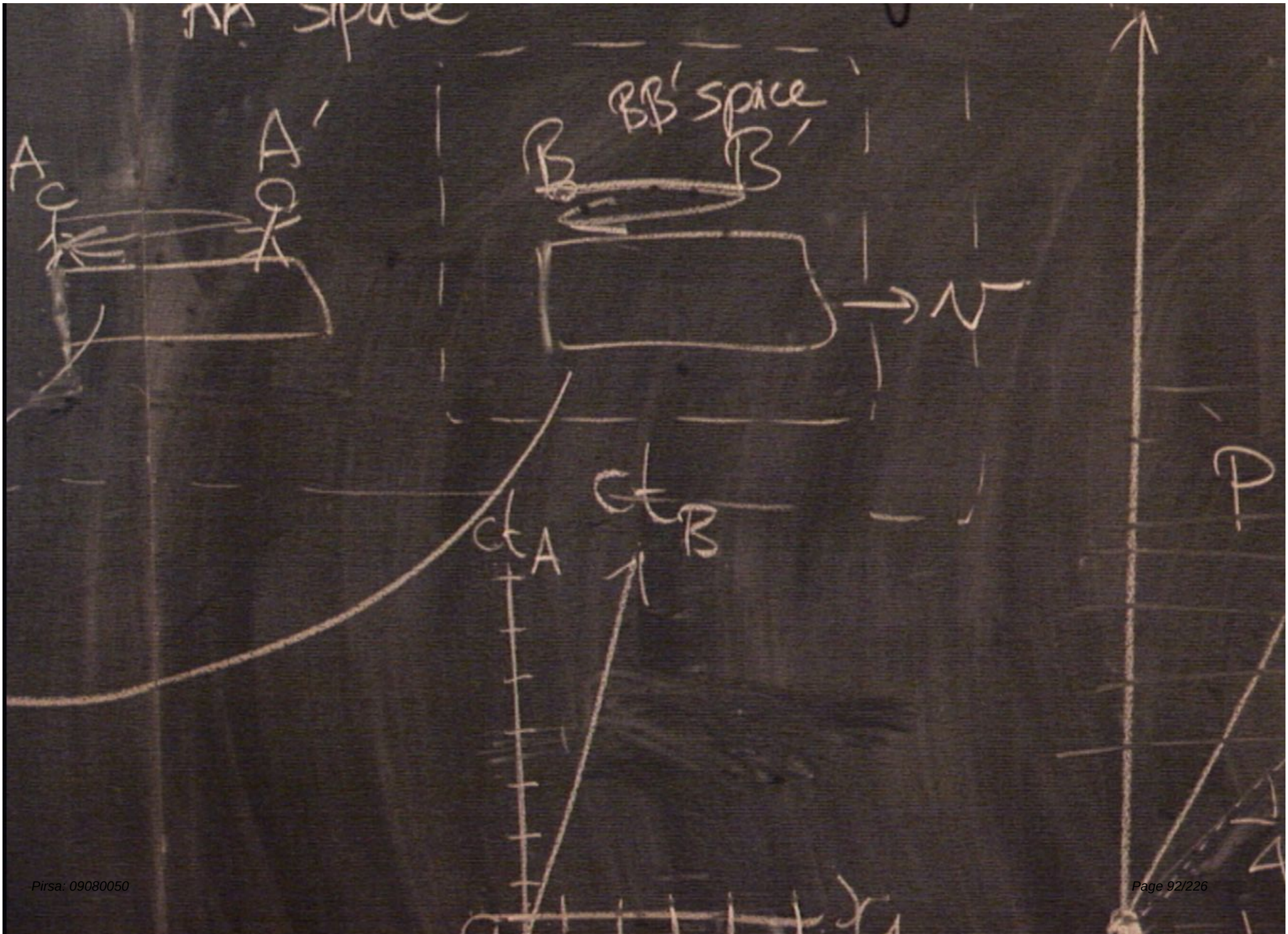

AA' space
BB' space
A
A'
B
B'
A
P

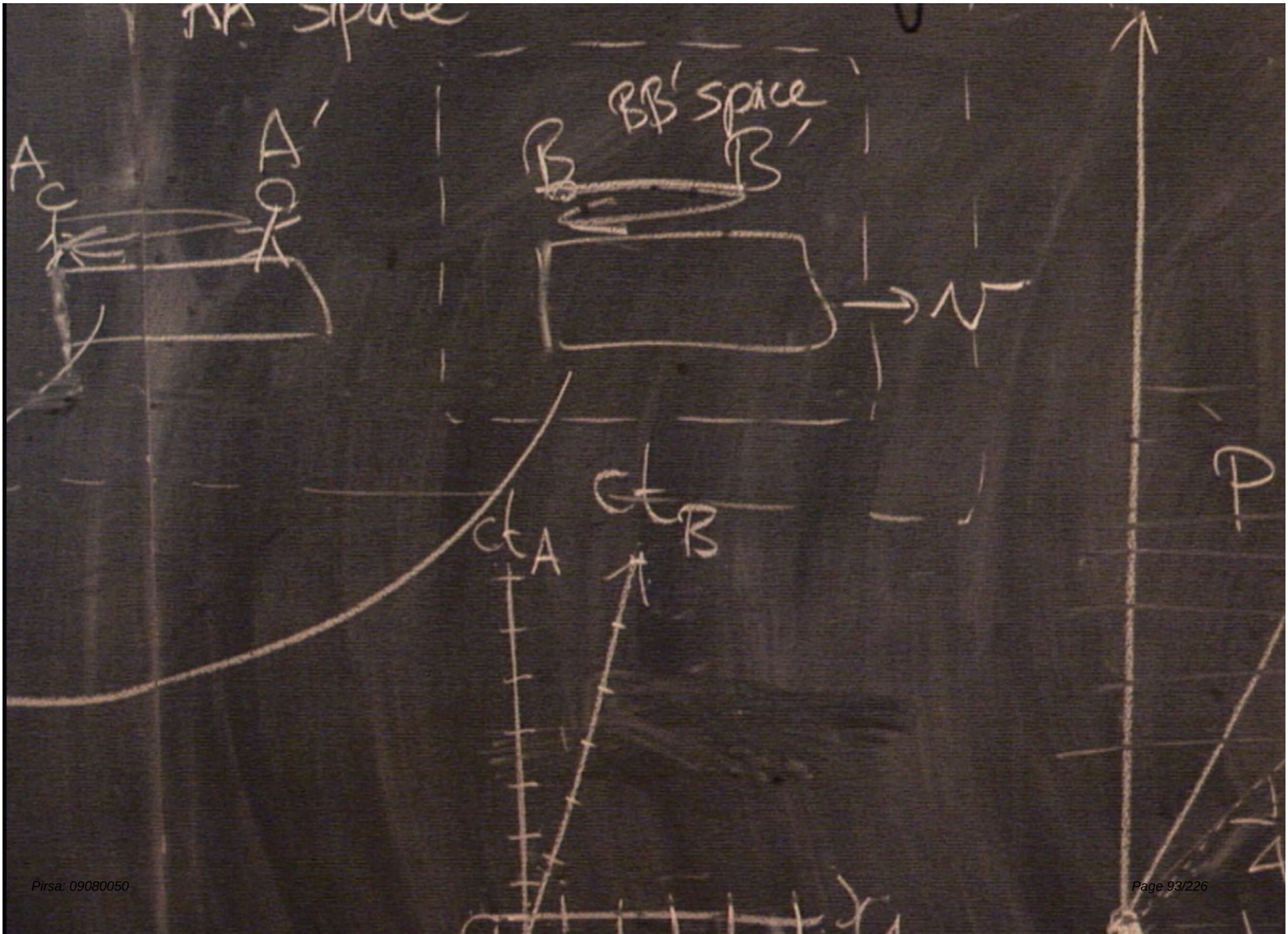

AA' space
BB' space
A
A'
B
B'
ct
A
P


AA' space
A
A'
BB' space
B
B'
ct
A
P

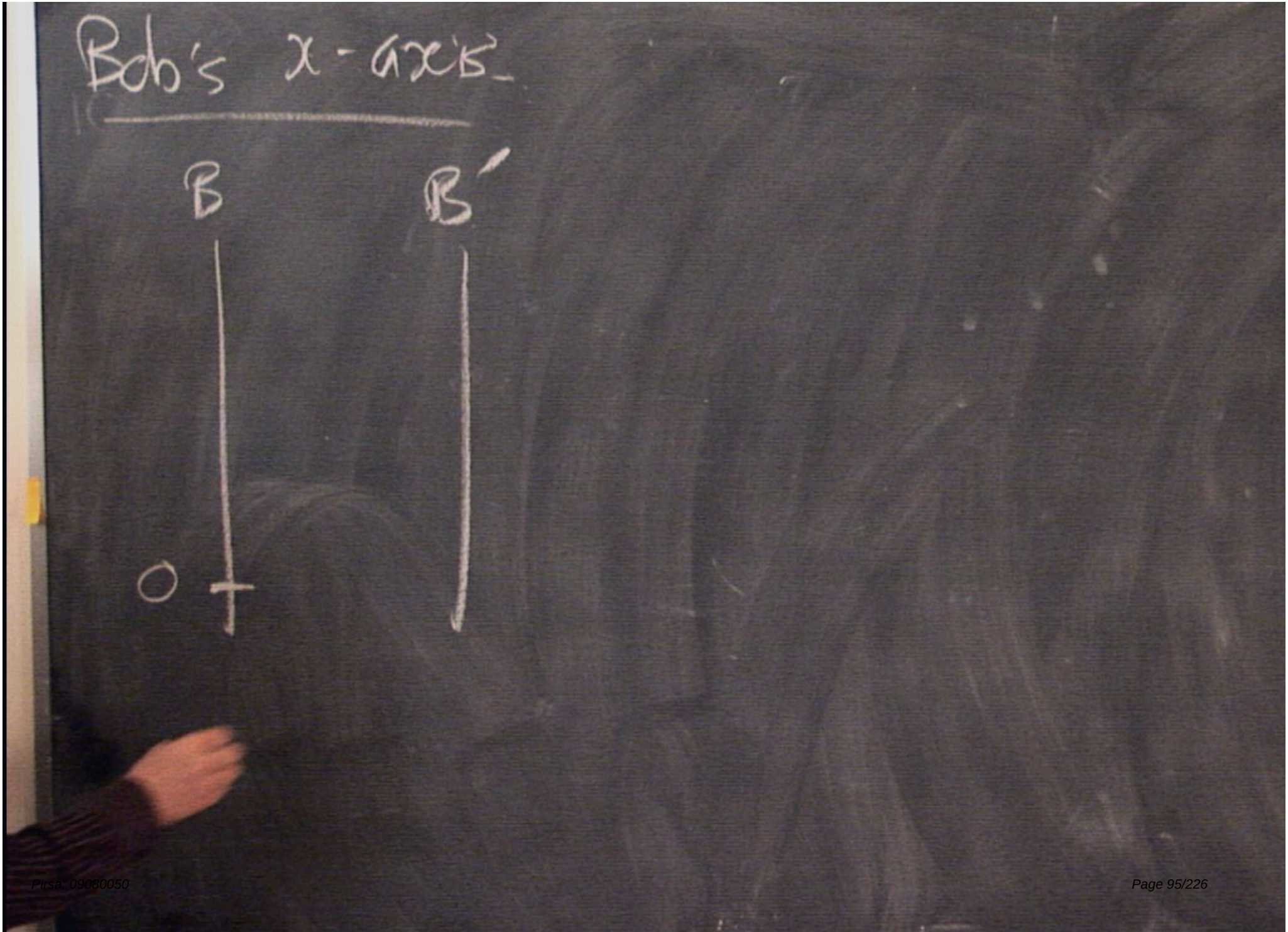

AA' space
BB' space
A
A'
B
B'
ct
A
P

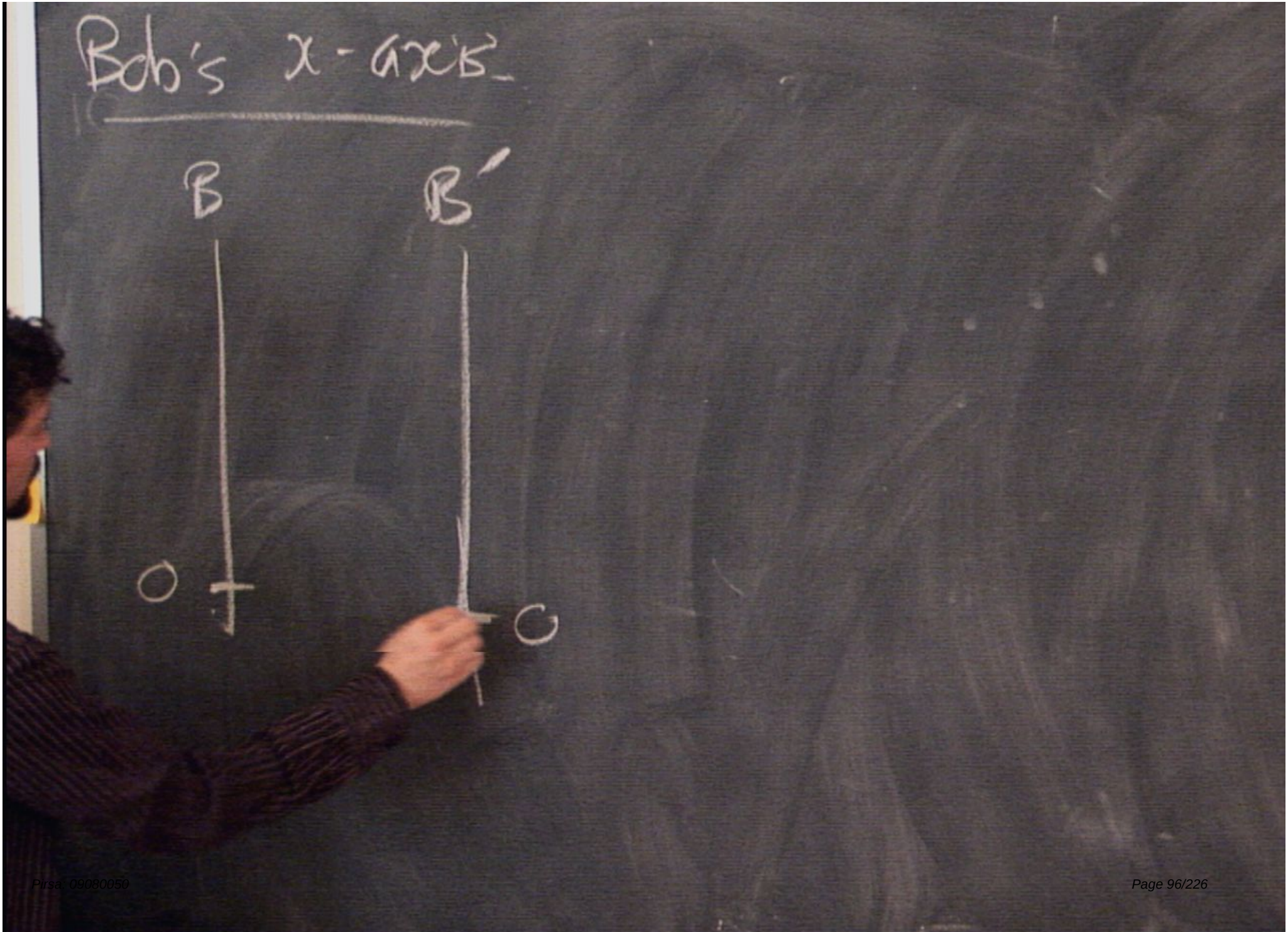

AA' space
BB' space
A
A'
B
B'
ct
A
ct
B
P

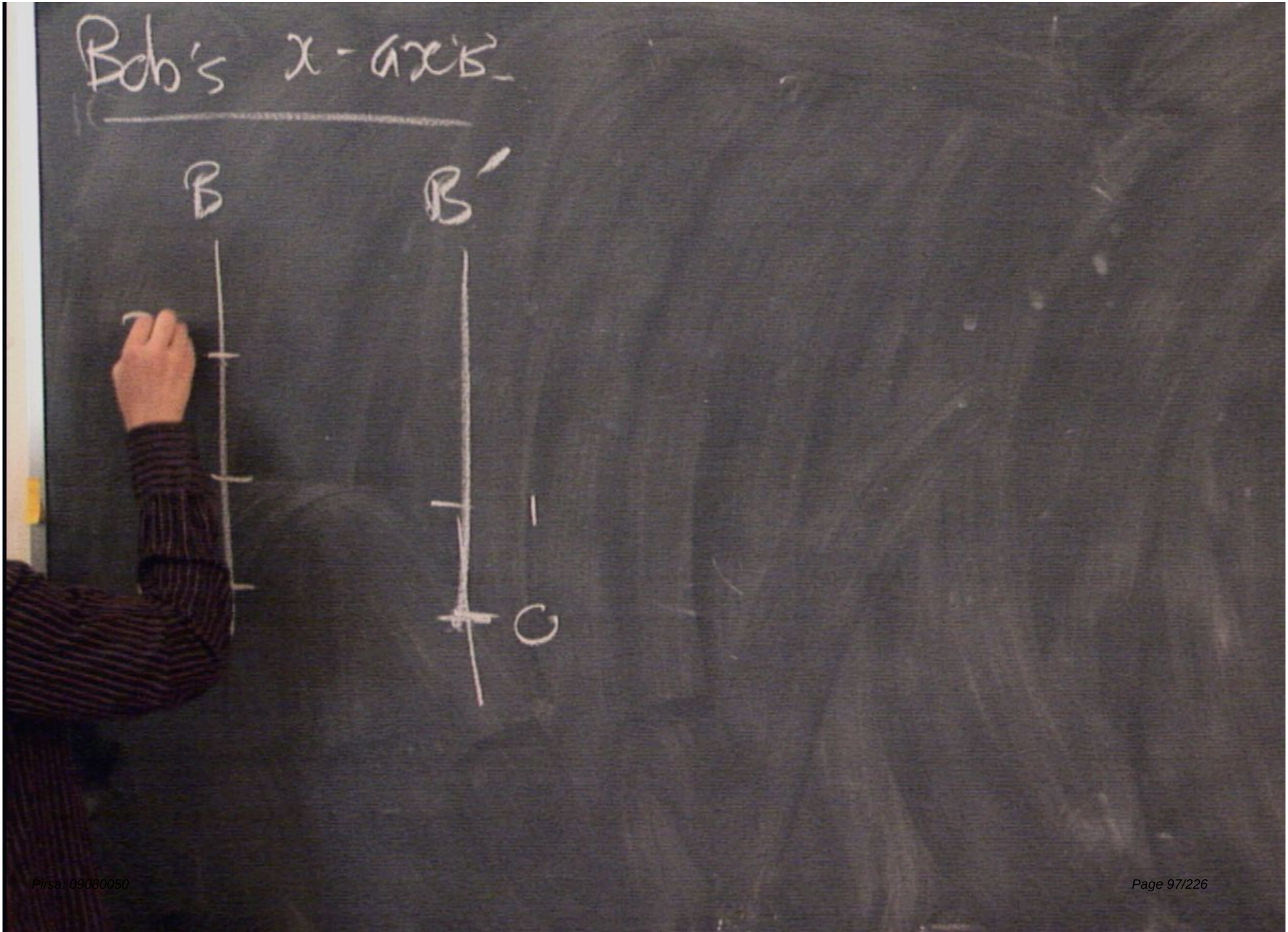

AA' space
BB' space
A
A'
B
B'
ct_A
ct_B
P


AA' space
BB' space
A
A'
B
B'
v
A
B
P

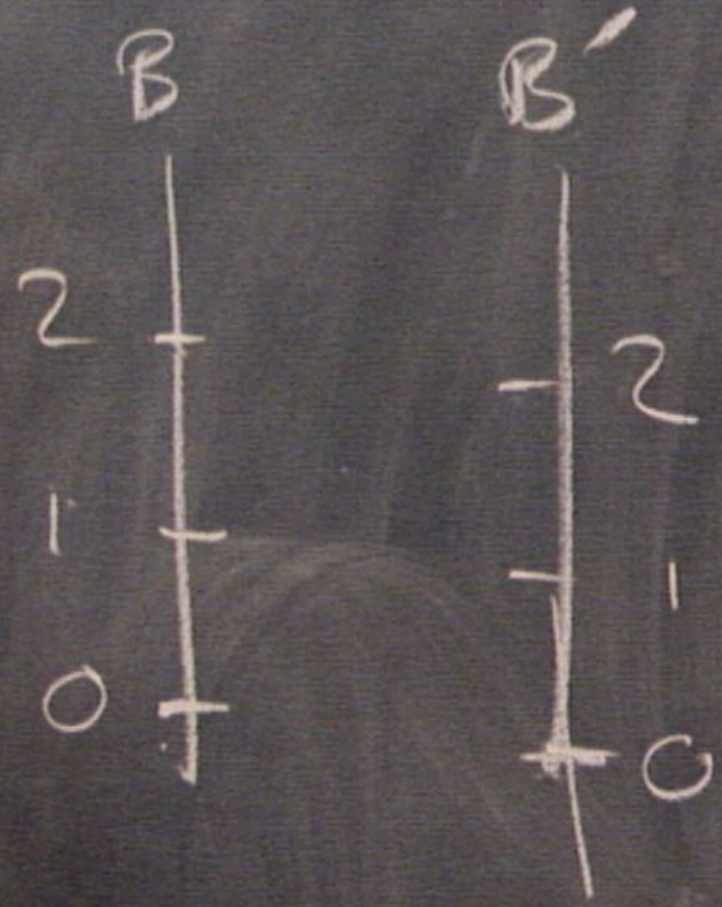
Bob's x-axis


Bob's x-axis
B
B'
O

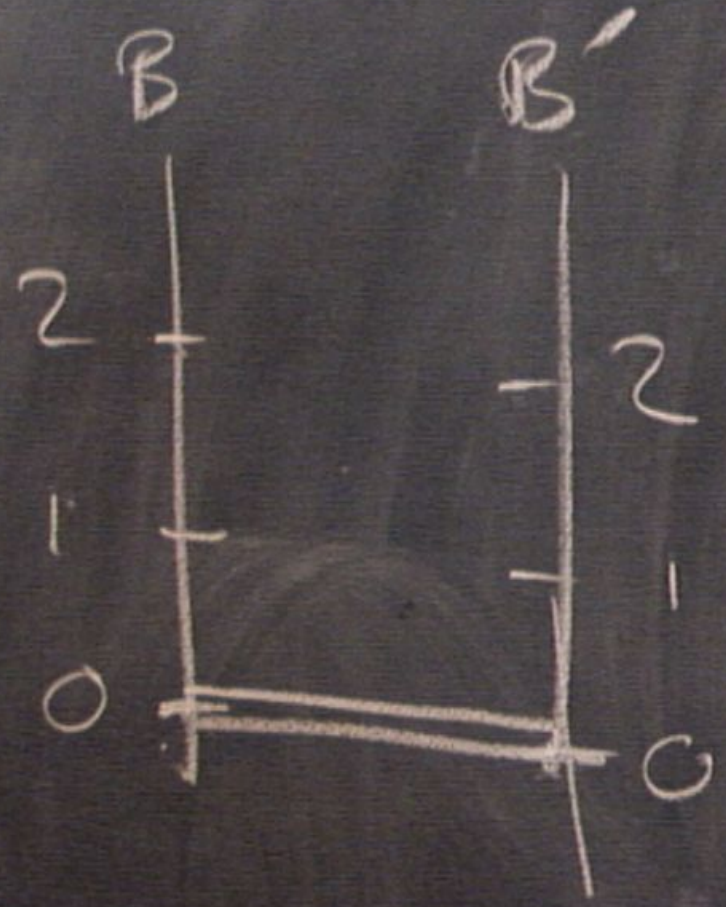

Bob's x-axis
B
B'
O
C


Bob's x-axis
B
B'
C

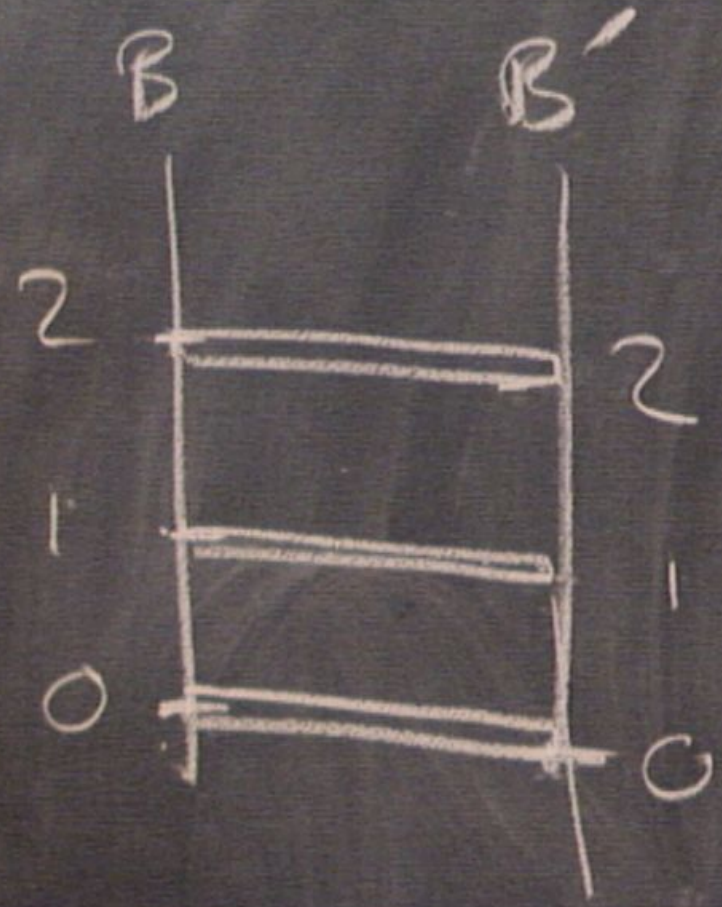
Bob's x-axis



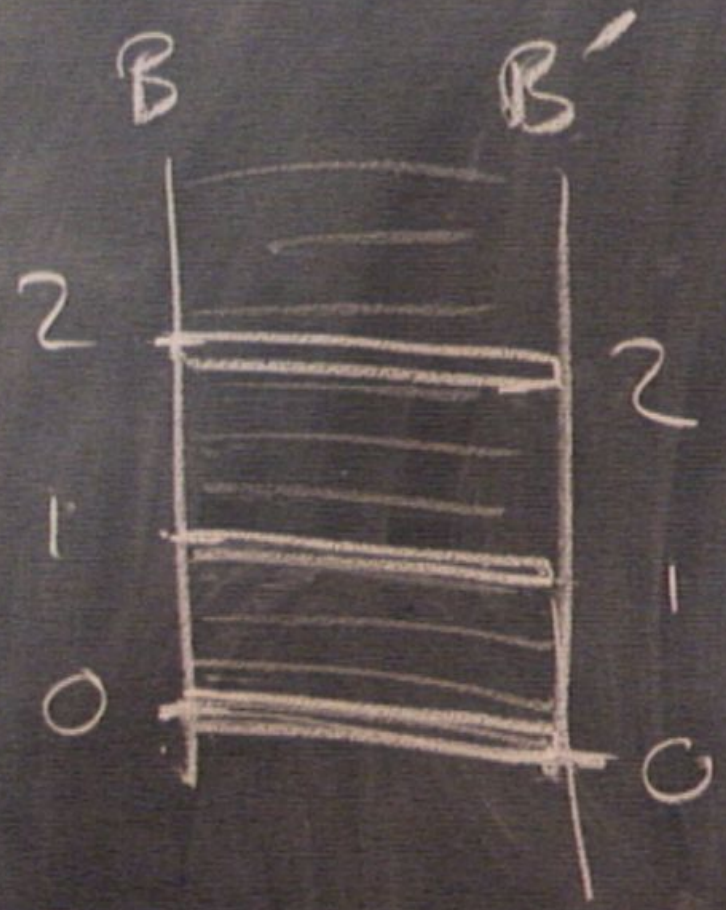
Bdb's x-GXB



Bob's x-GXB

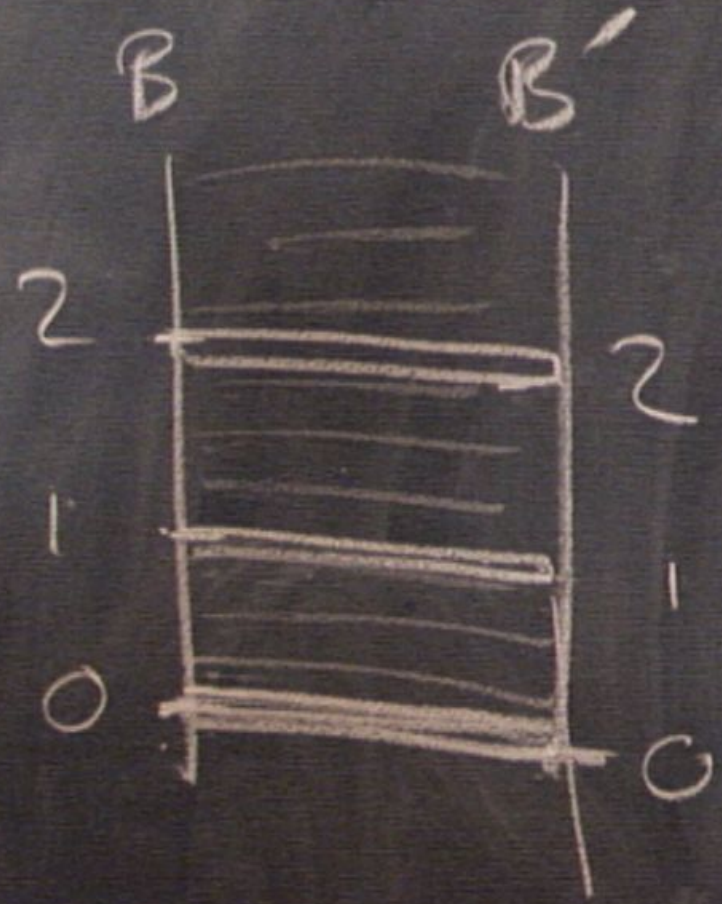


Bdb's x-GXB

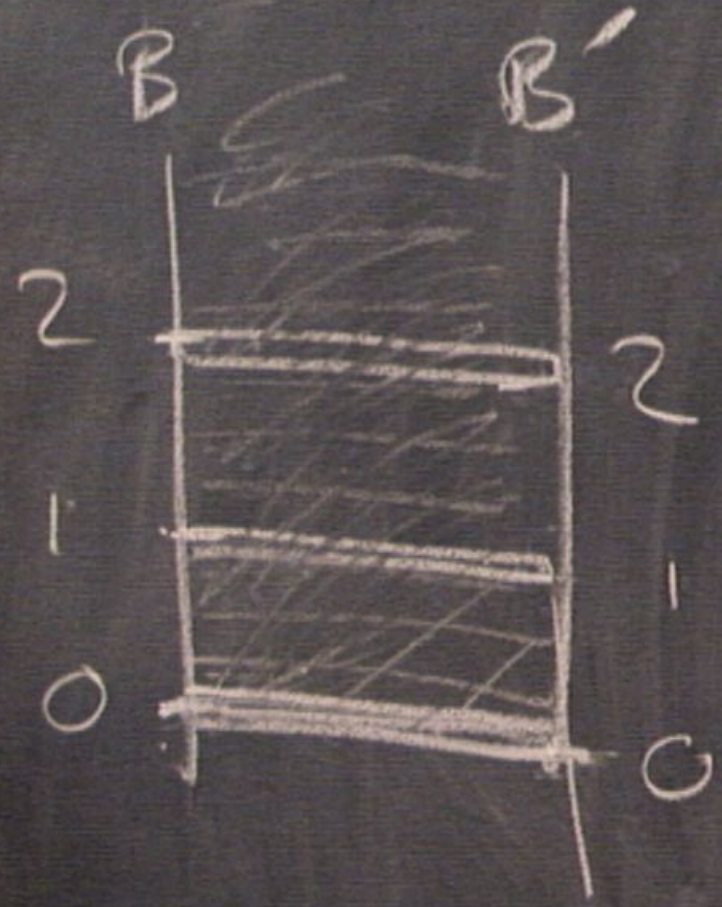



Bob's X-GXB
B
B'
2
2
1
1
0

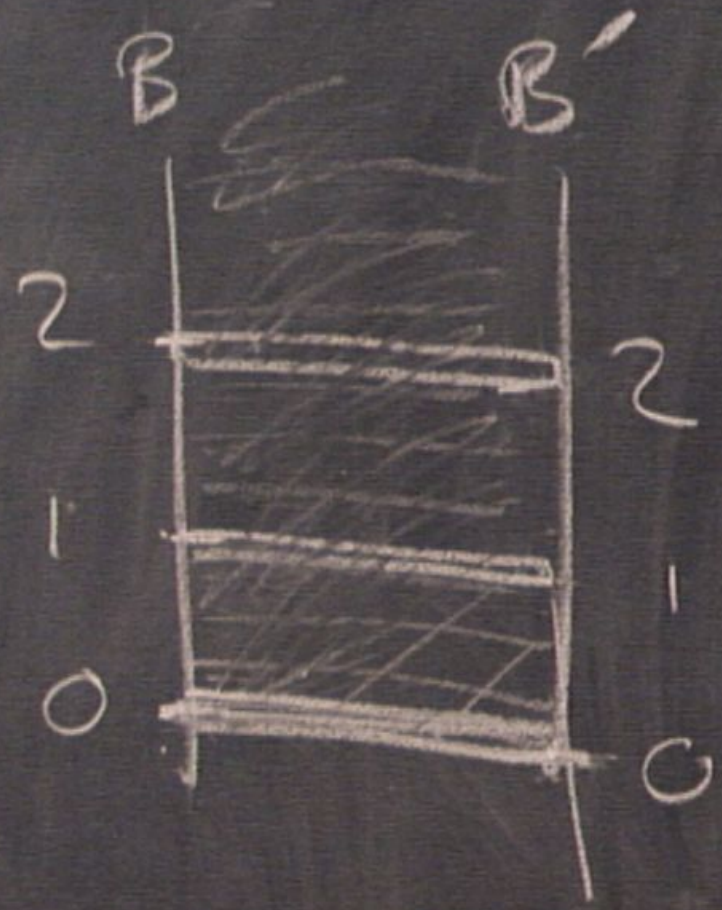
Bob's X-GXB

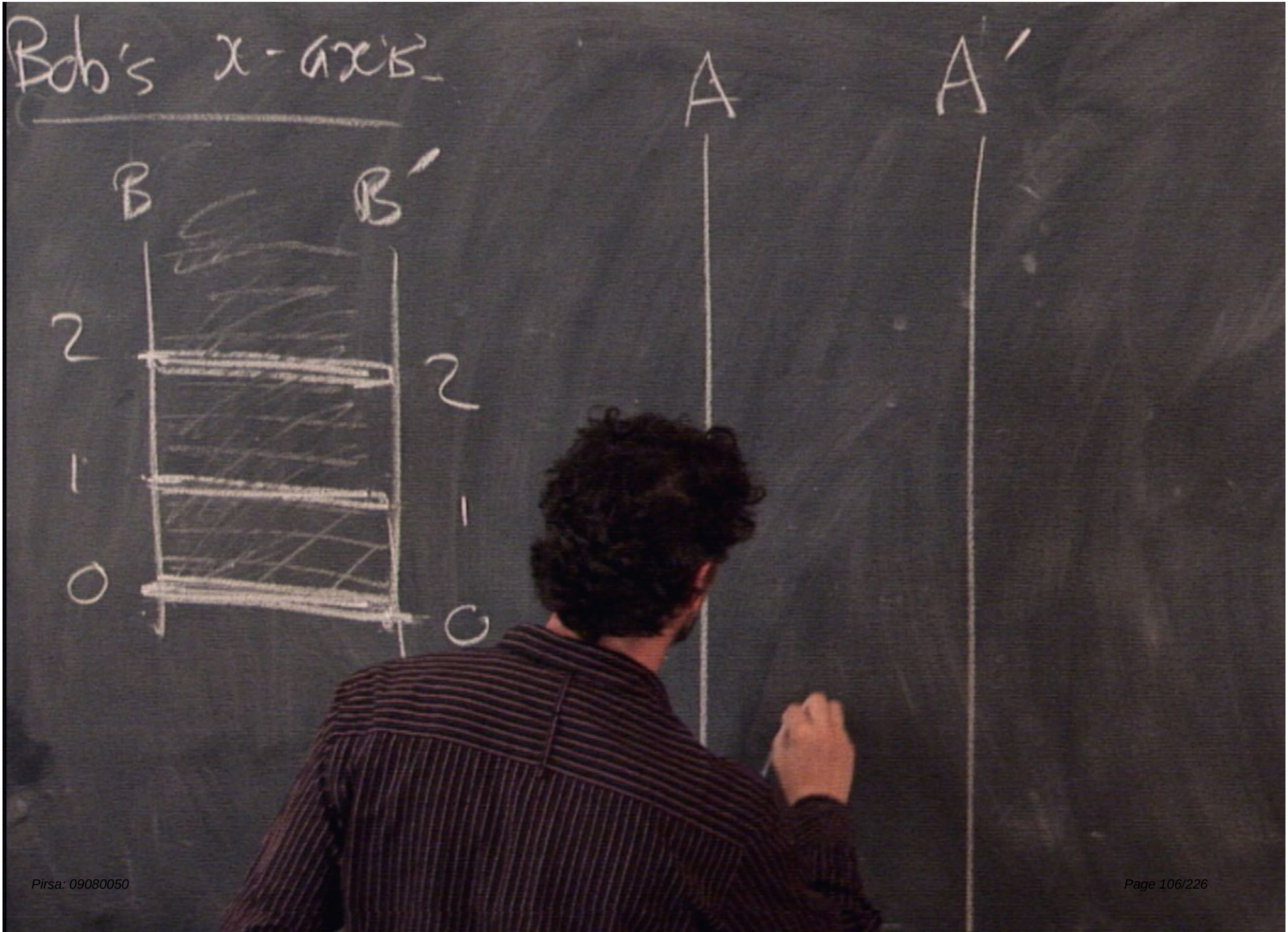


Bob's X-GXB

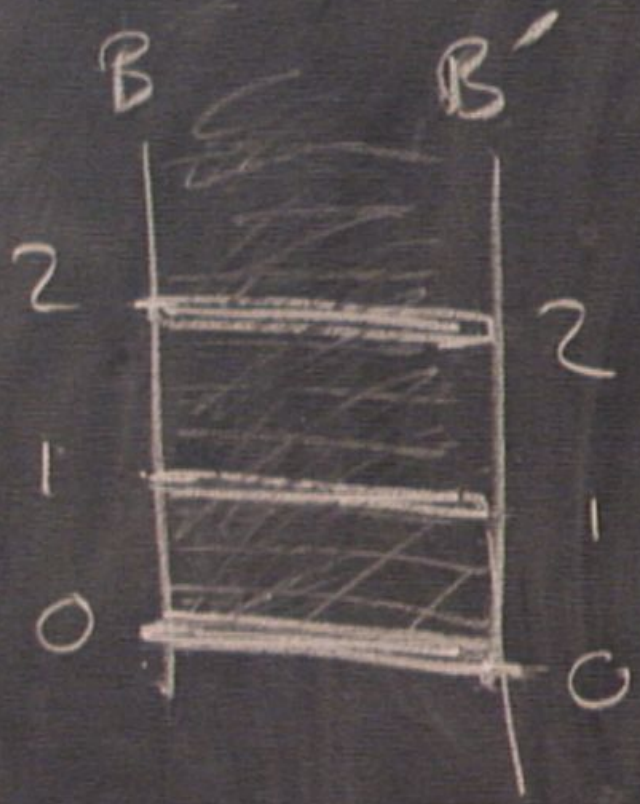


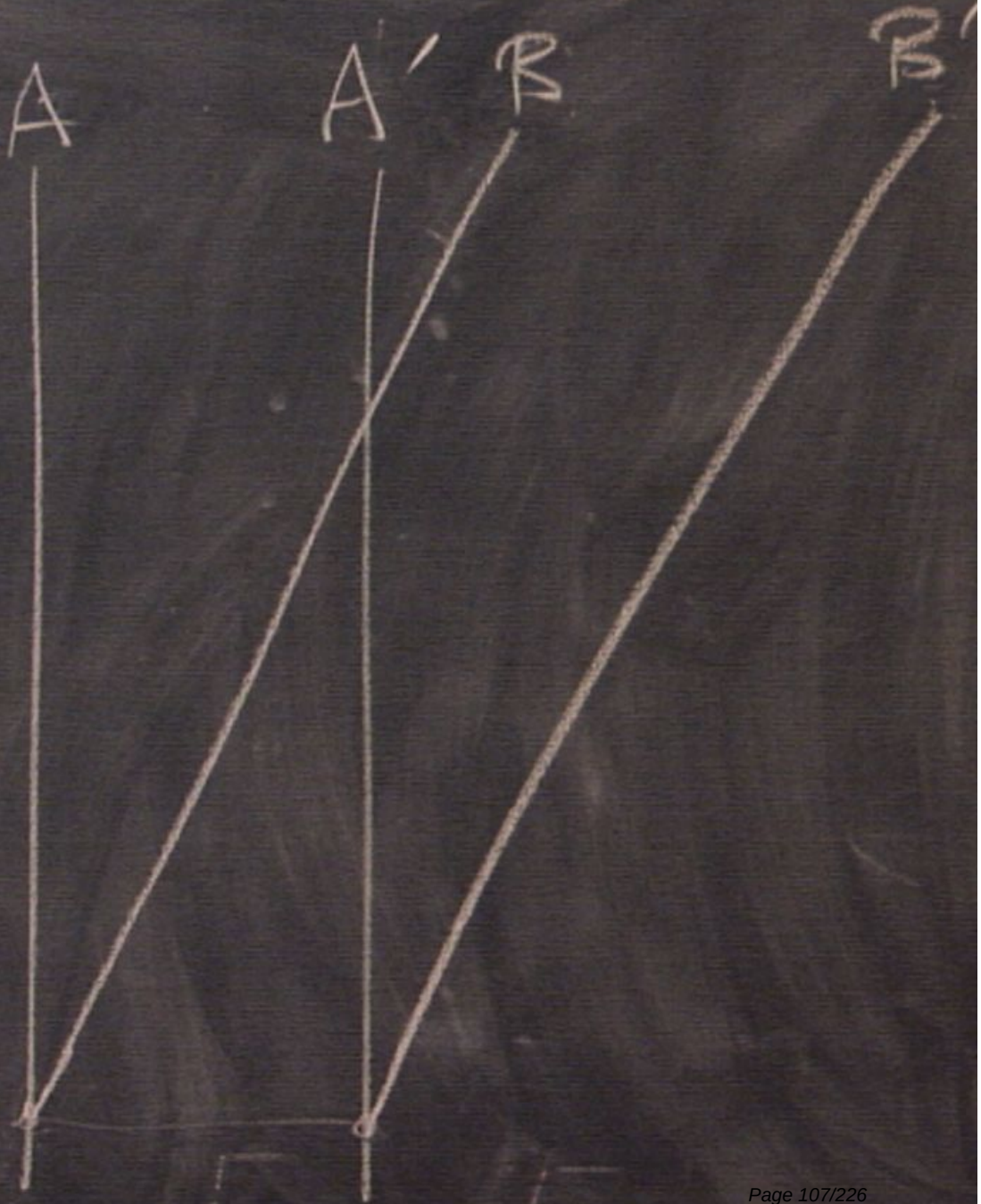
Bob's X-GXB

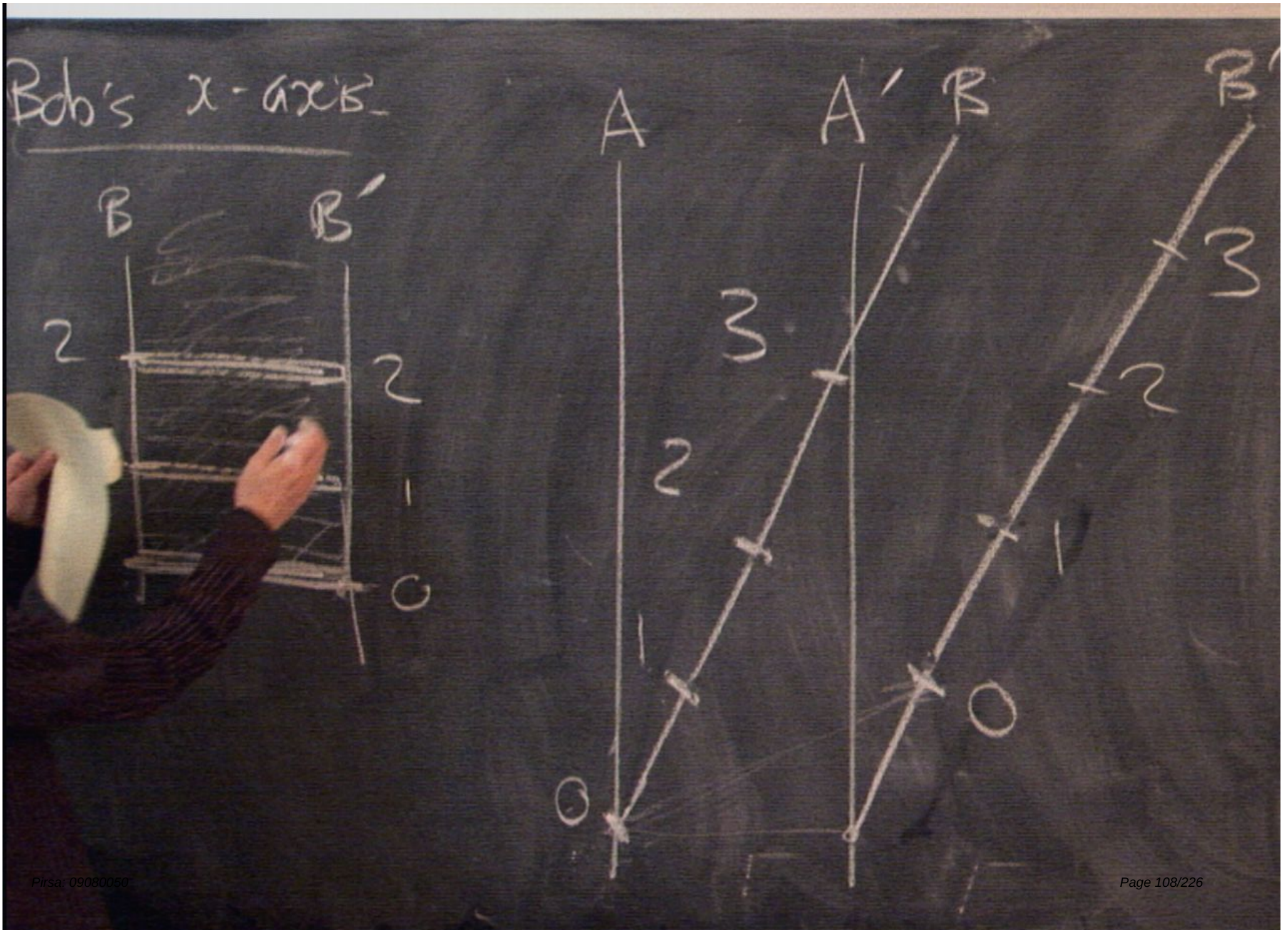



Bob's x-GXB
A
A'
B
B'
2
2
1
1
0
0

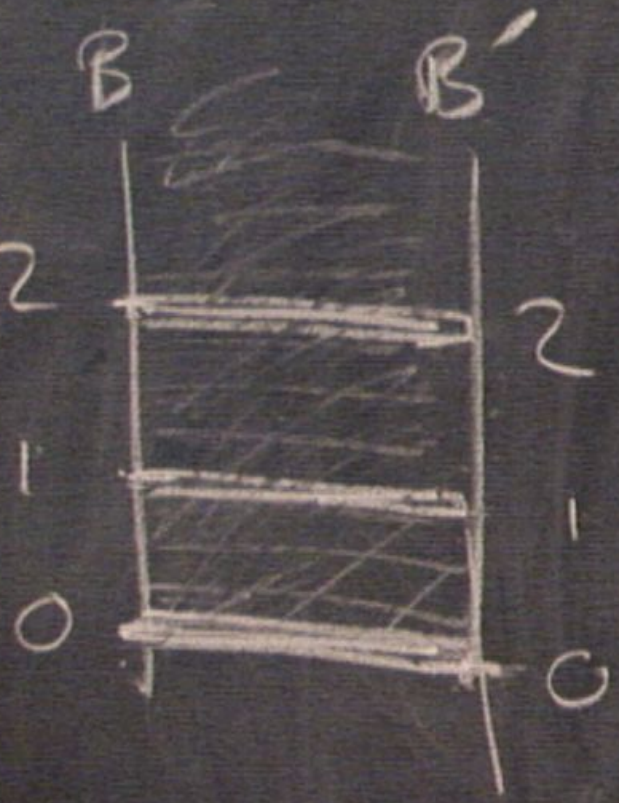
Bdb's x-axis

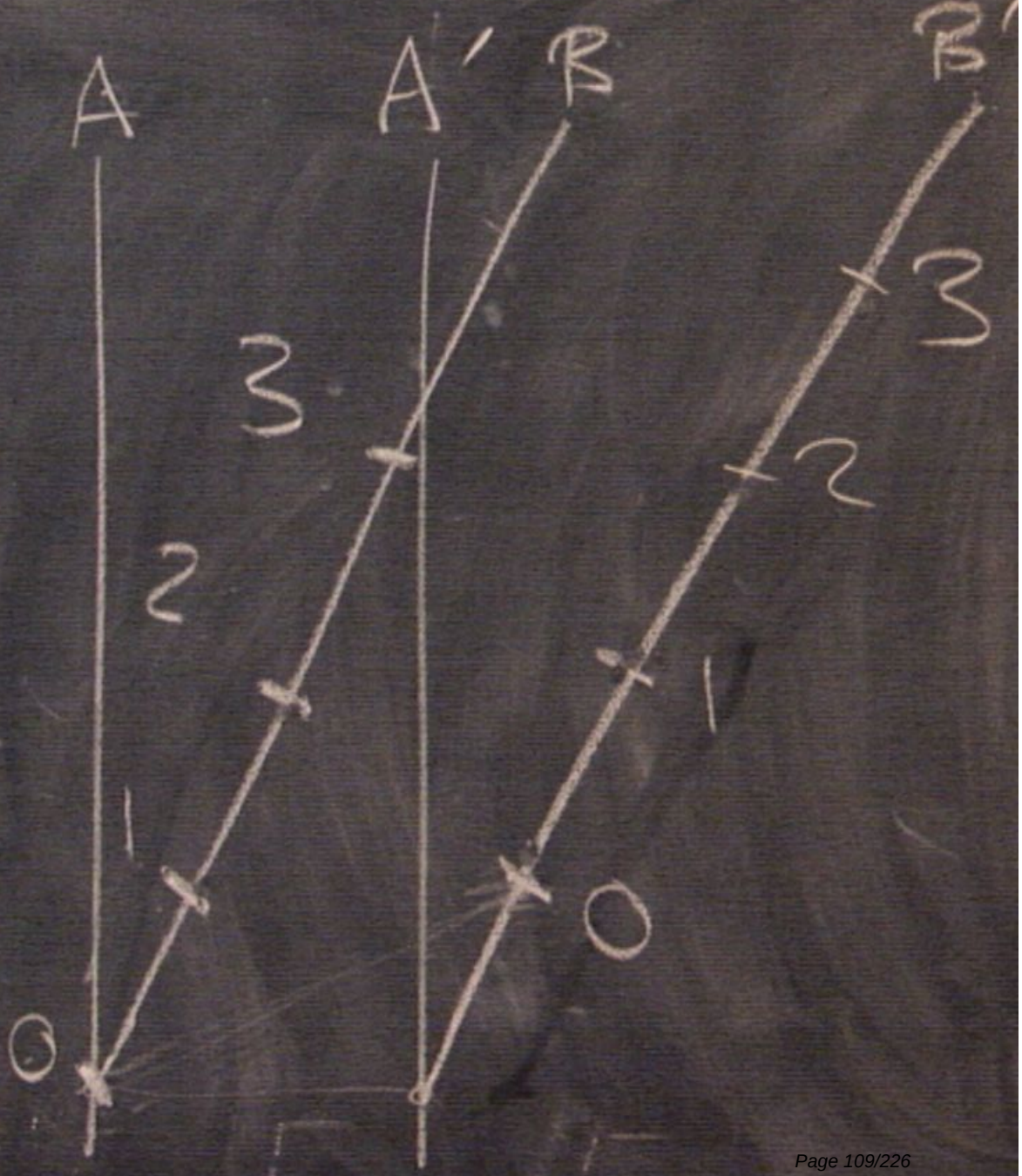


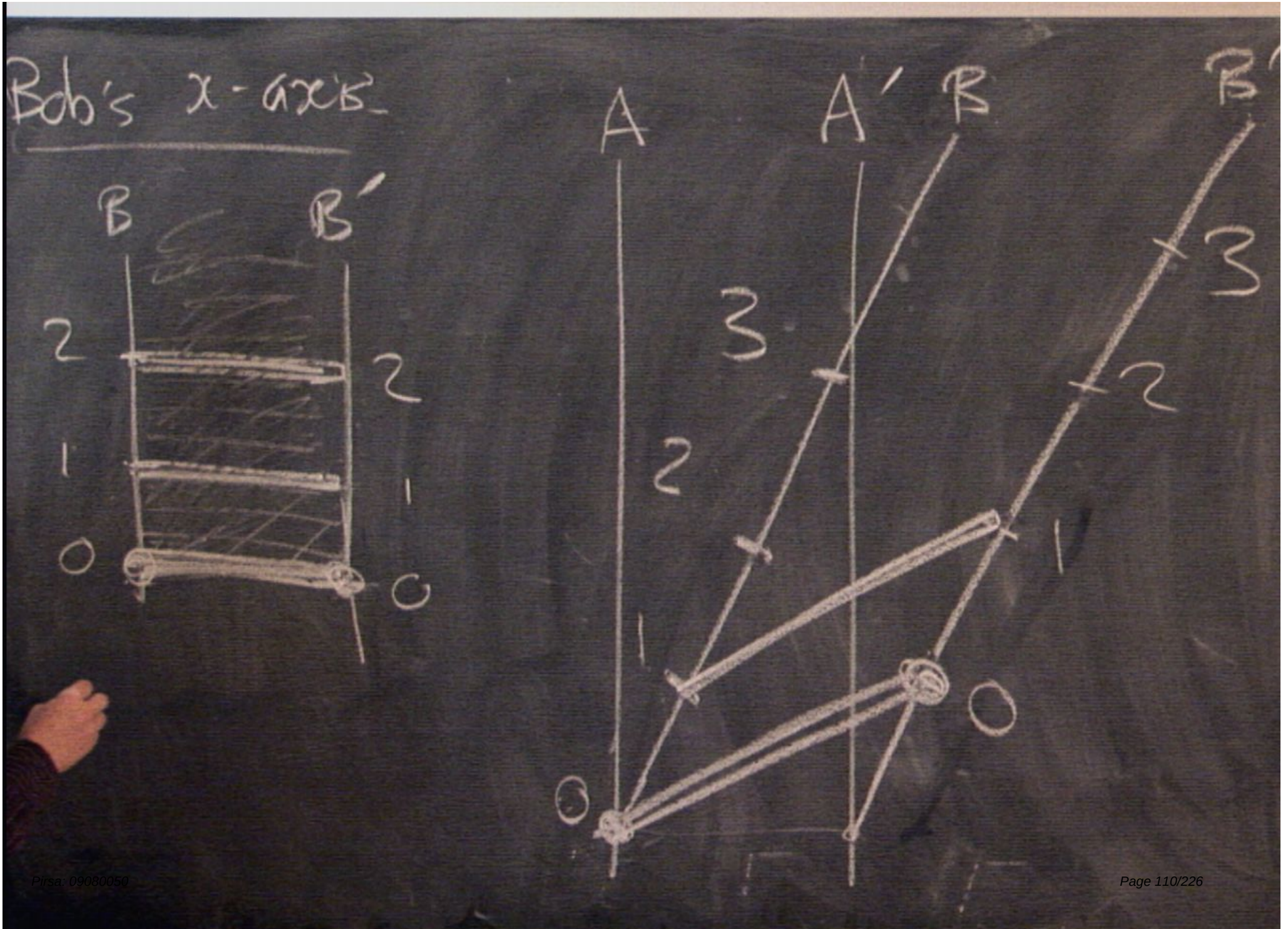



Bob's x-ray
B
B'
2
2
1
0
A
A'
B
B'
3
2
1
0
3
2
1
0

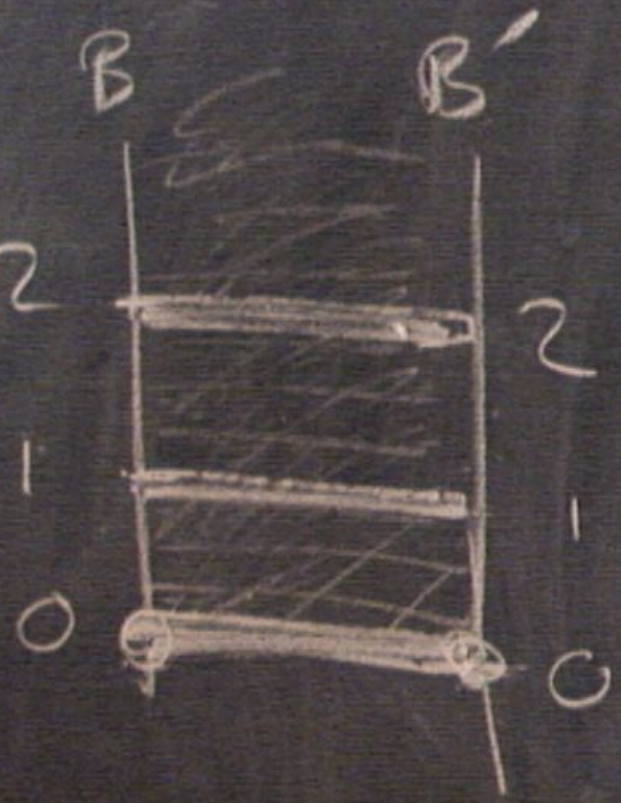
Bdb's x-axis

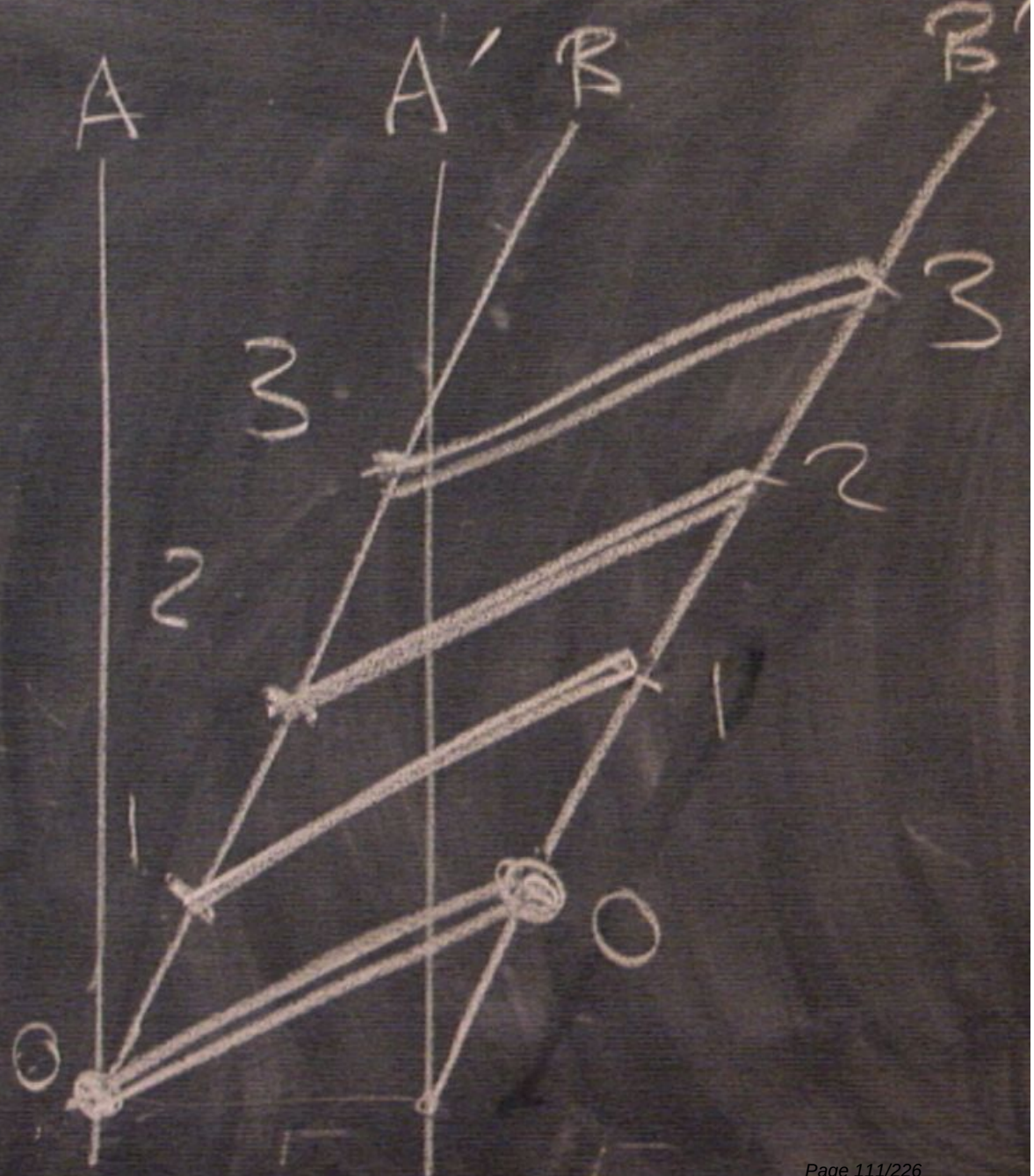




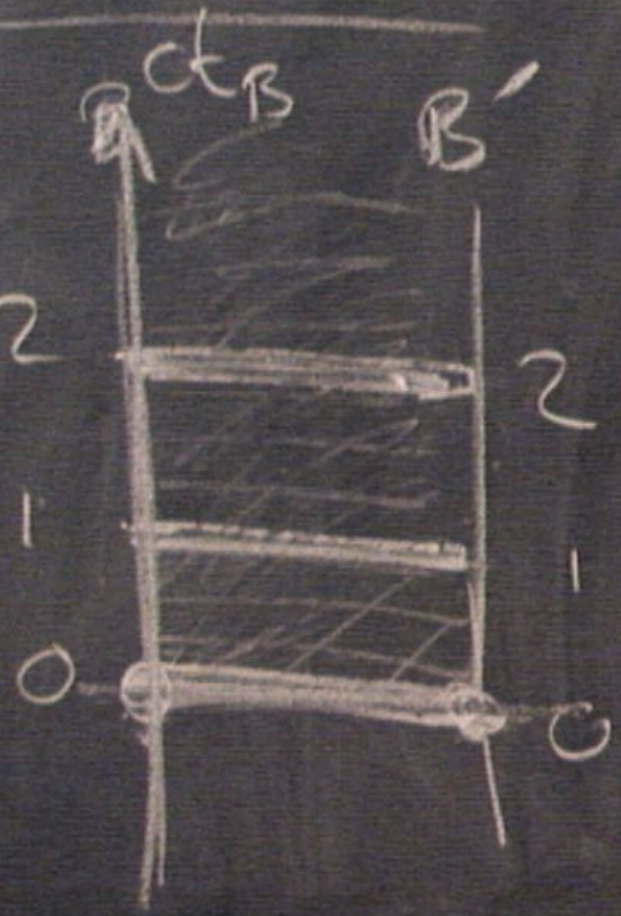

Bob's x-axis
B
B'
2
2
1
1
0
0
A
A'
B
B'
3
3
2
2
1
1
0
0

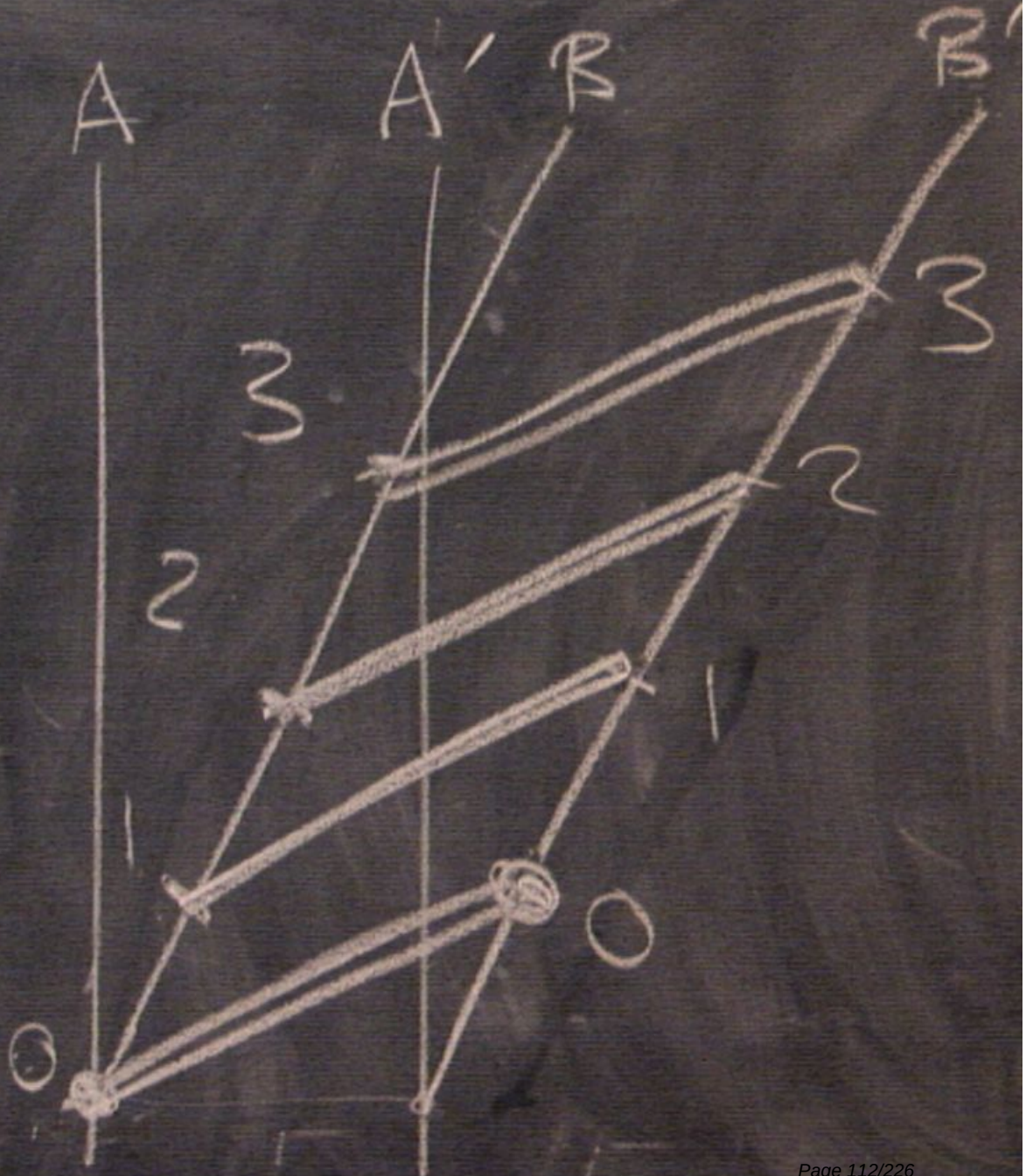
Bdb's x-axis

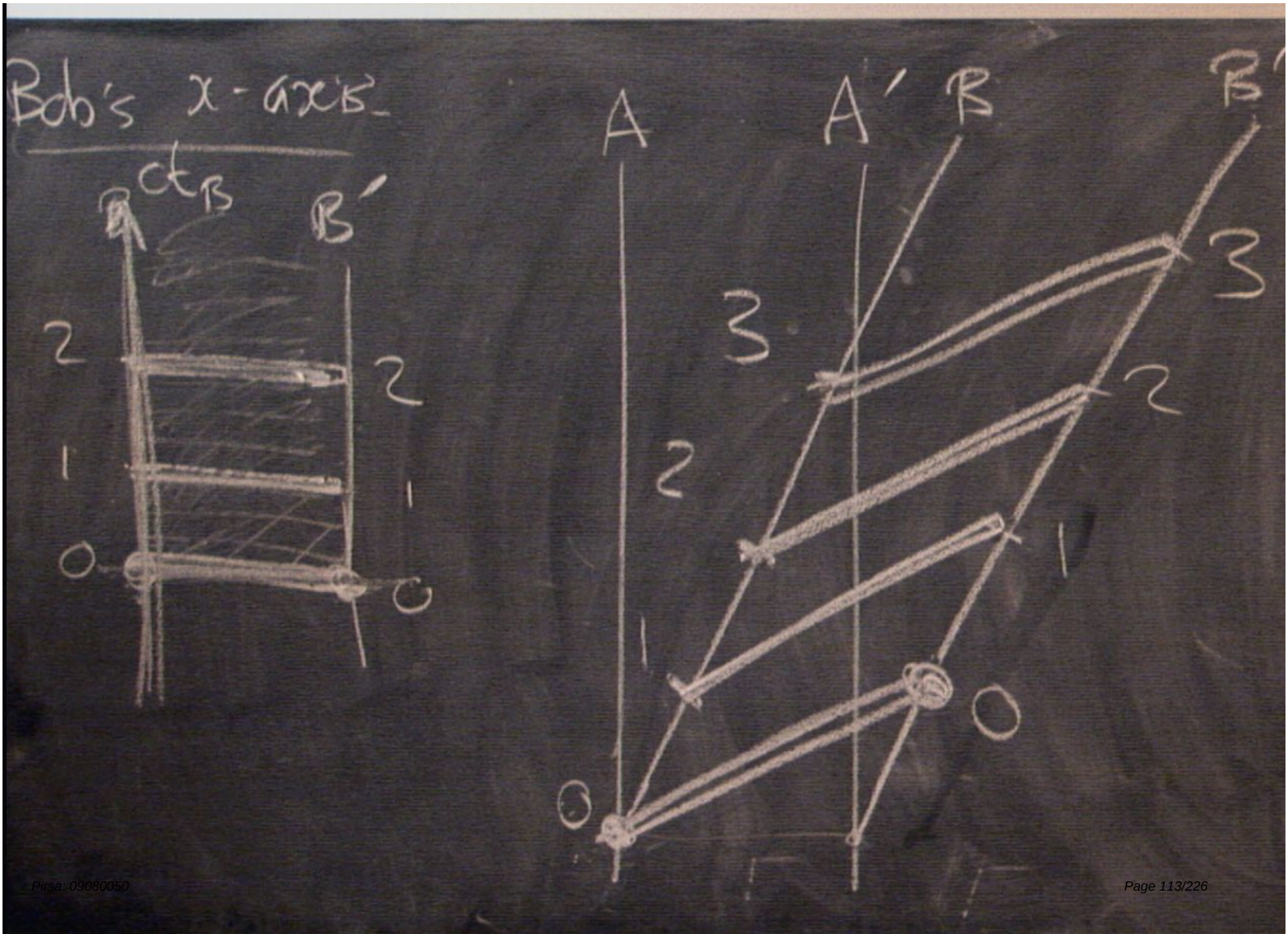


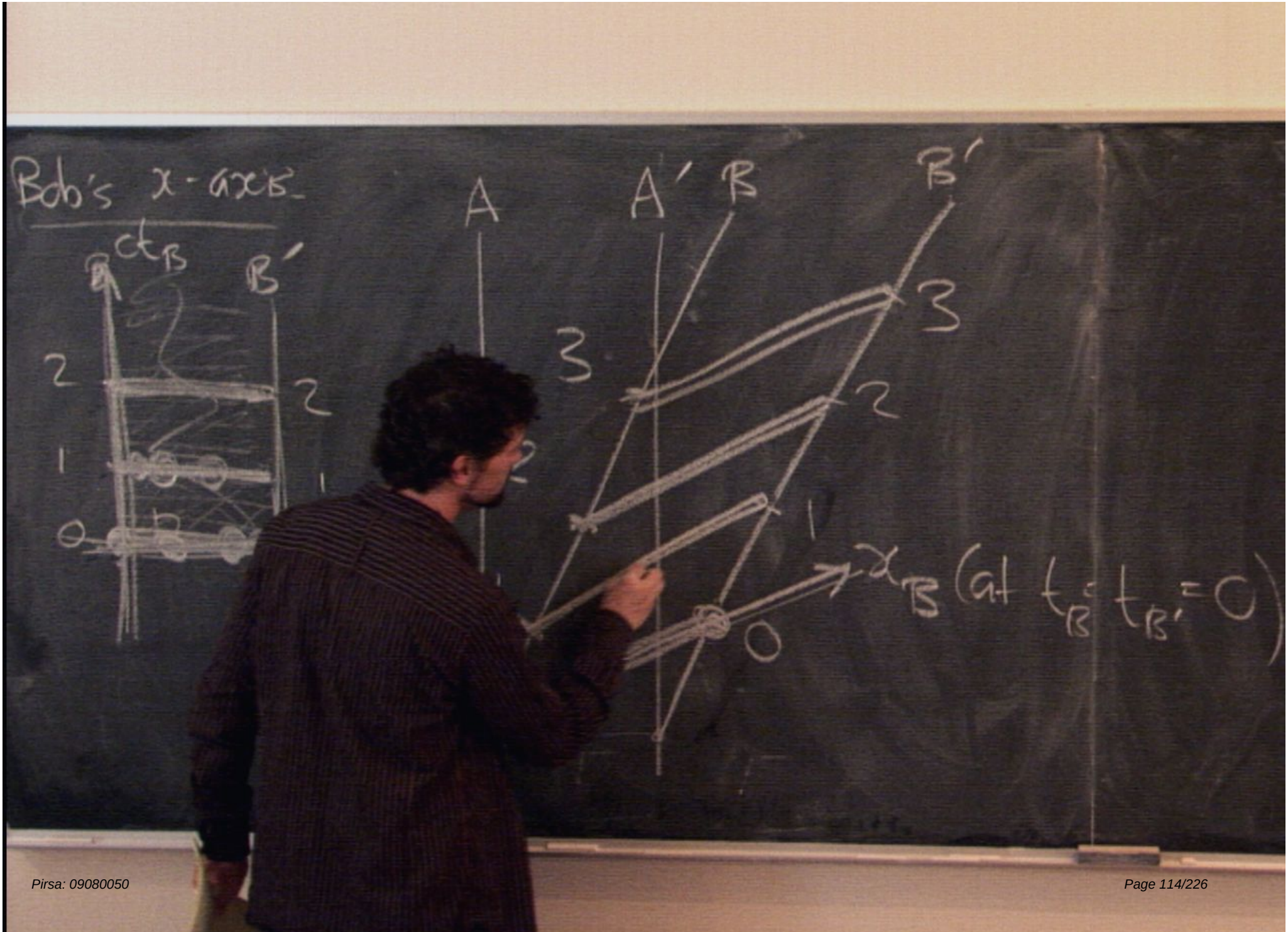


Bdy's x-axis

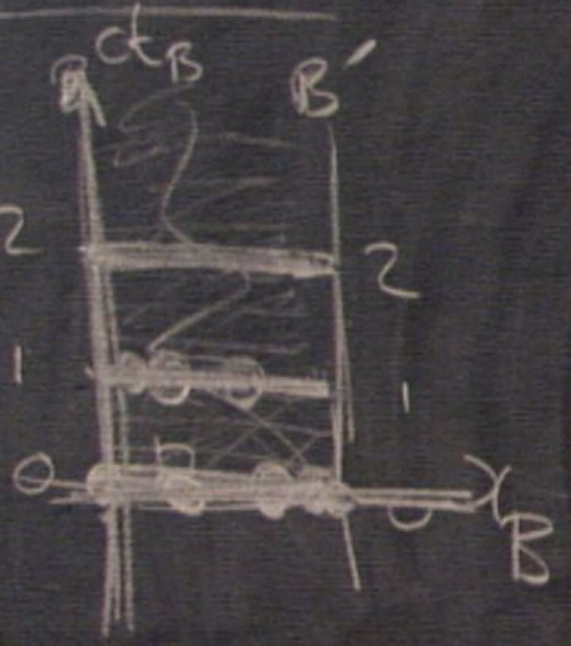


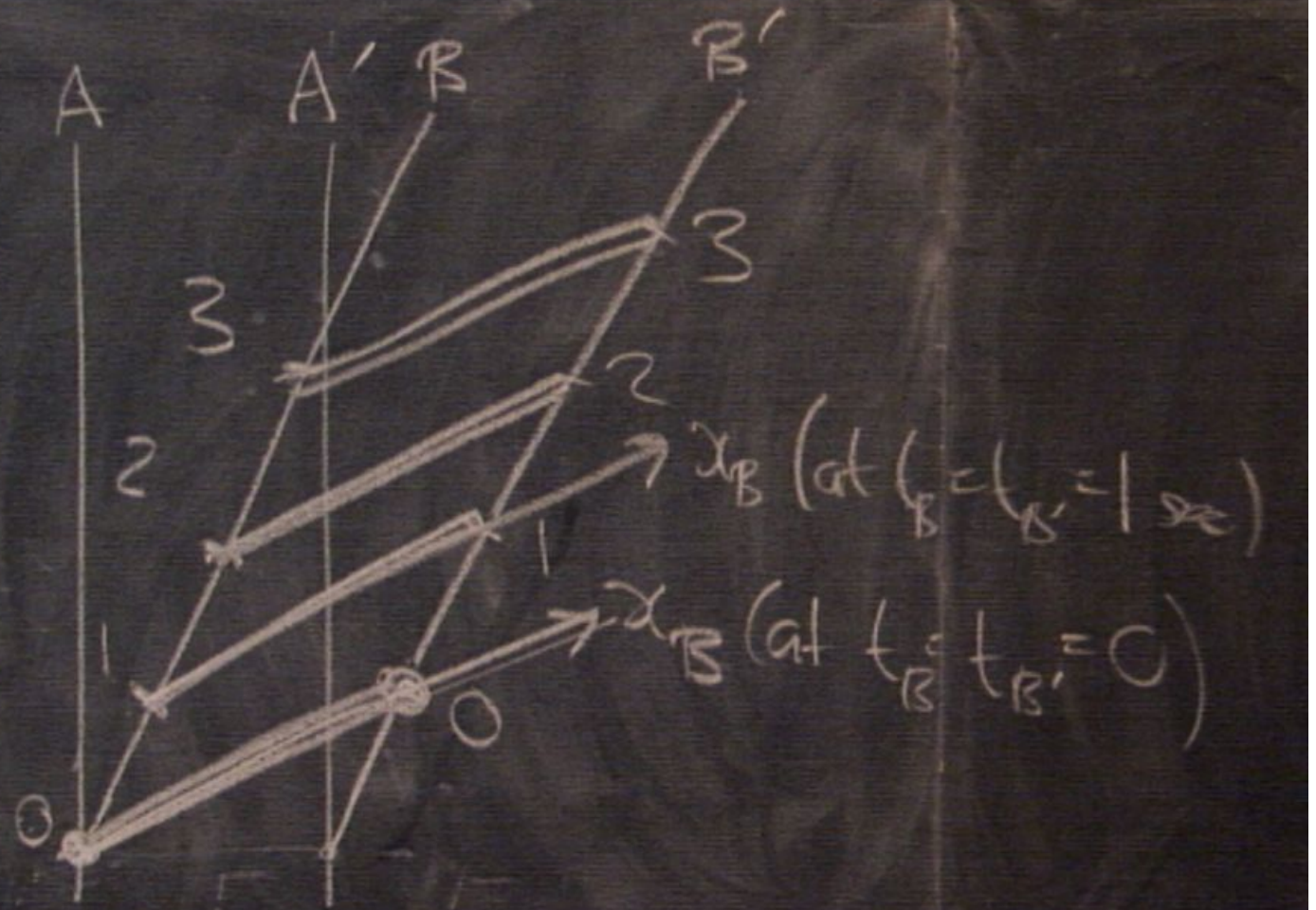


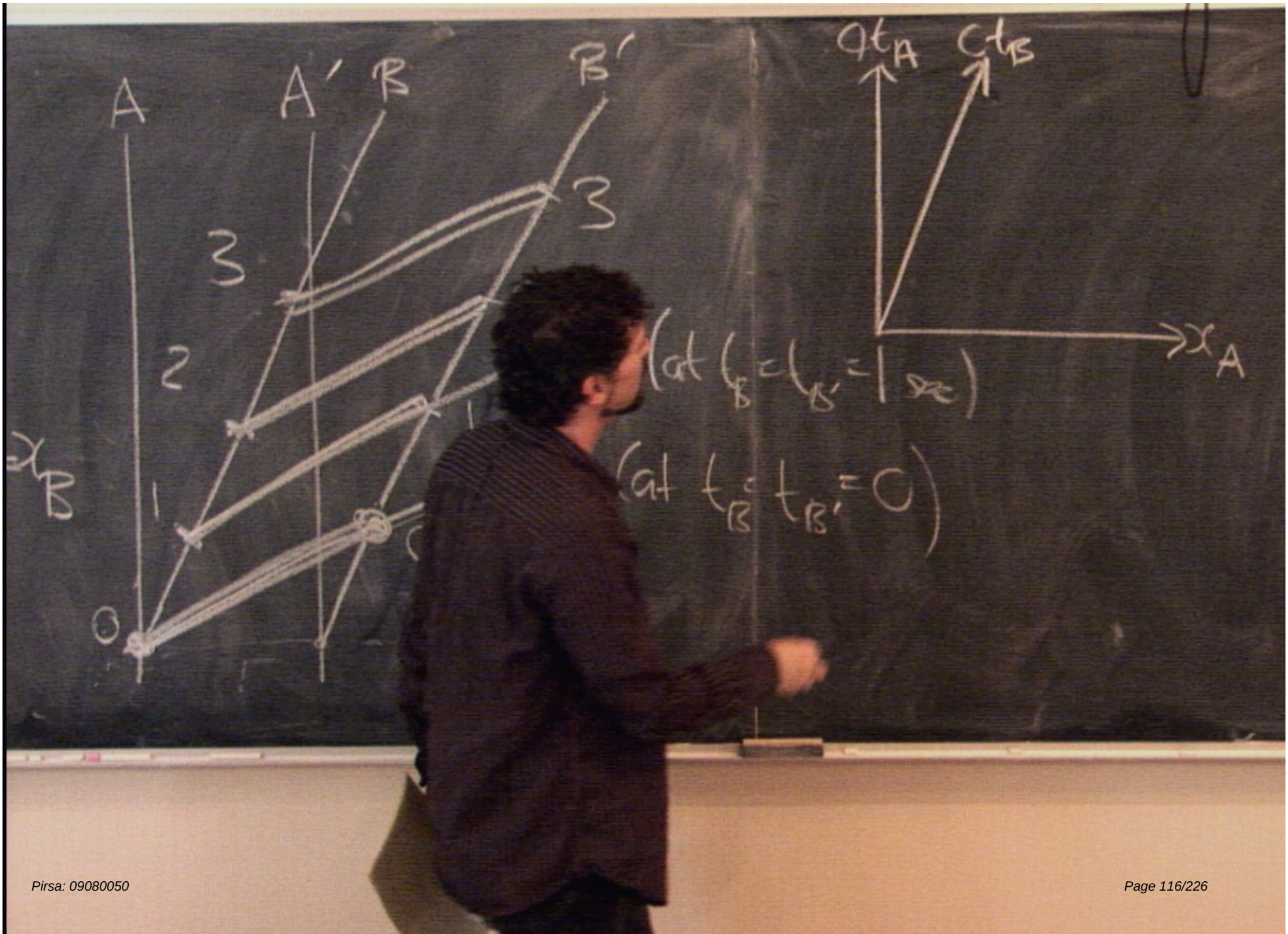

Bdb's x-axis
B
B'
2
2
1
1
0
0
A
A'
B
B'
3
3
2
2
1
1
0
0

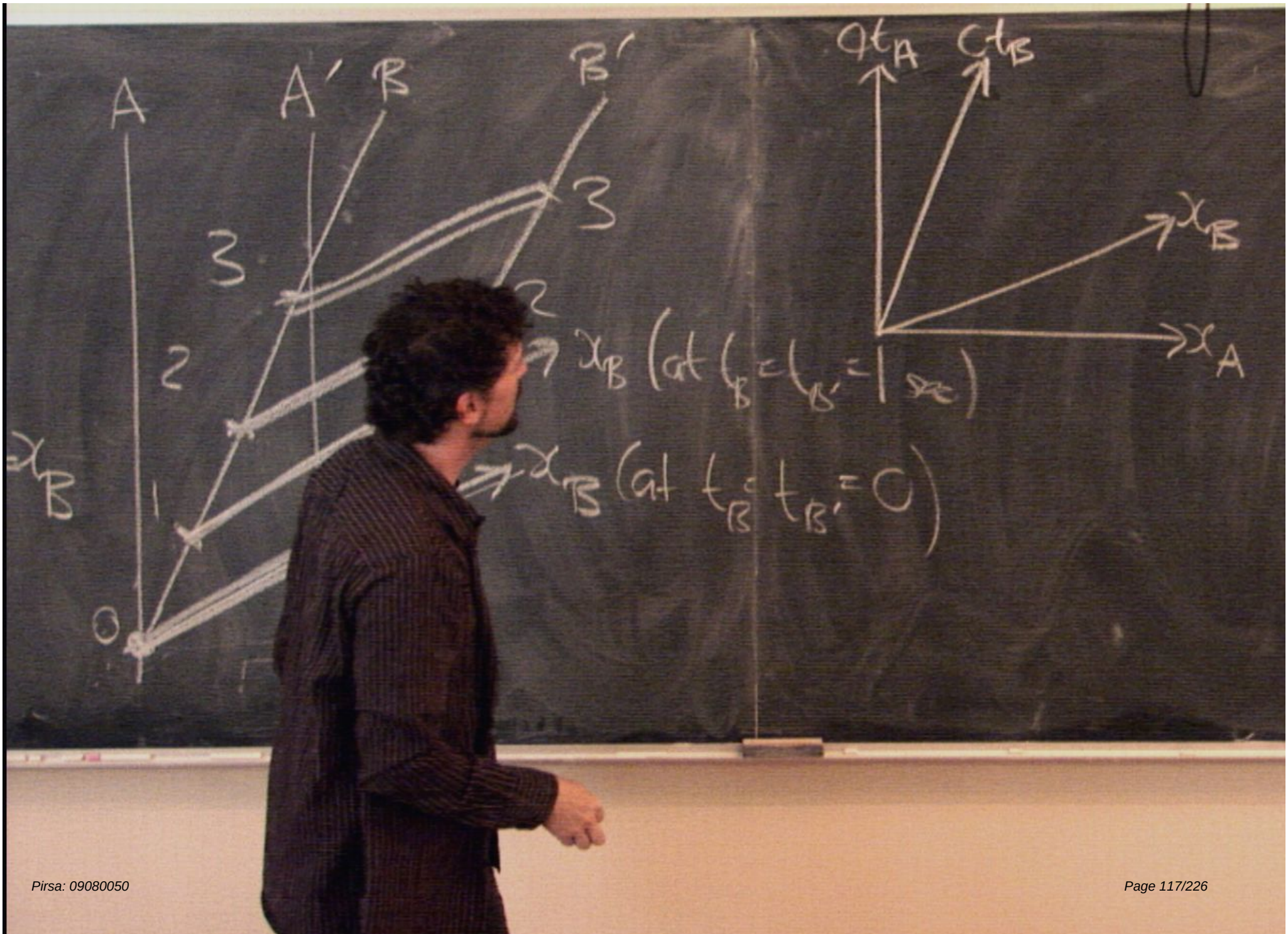

Bob's x - axis
ct_B
B
B'
2
1
0
A
A'
B
B'
3
2
1
0
x_B (at t_B = t_B' = 0)

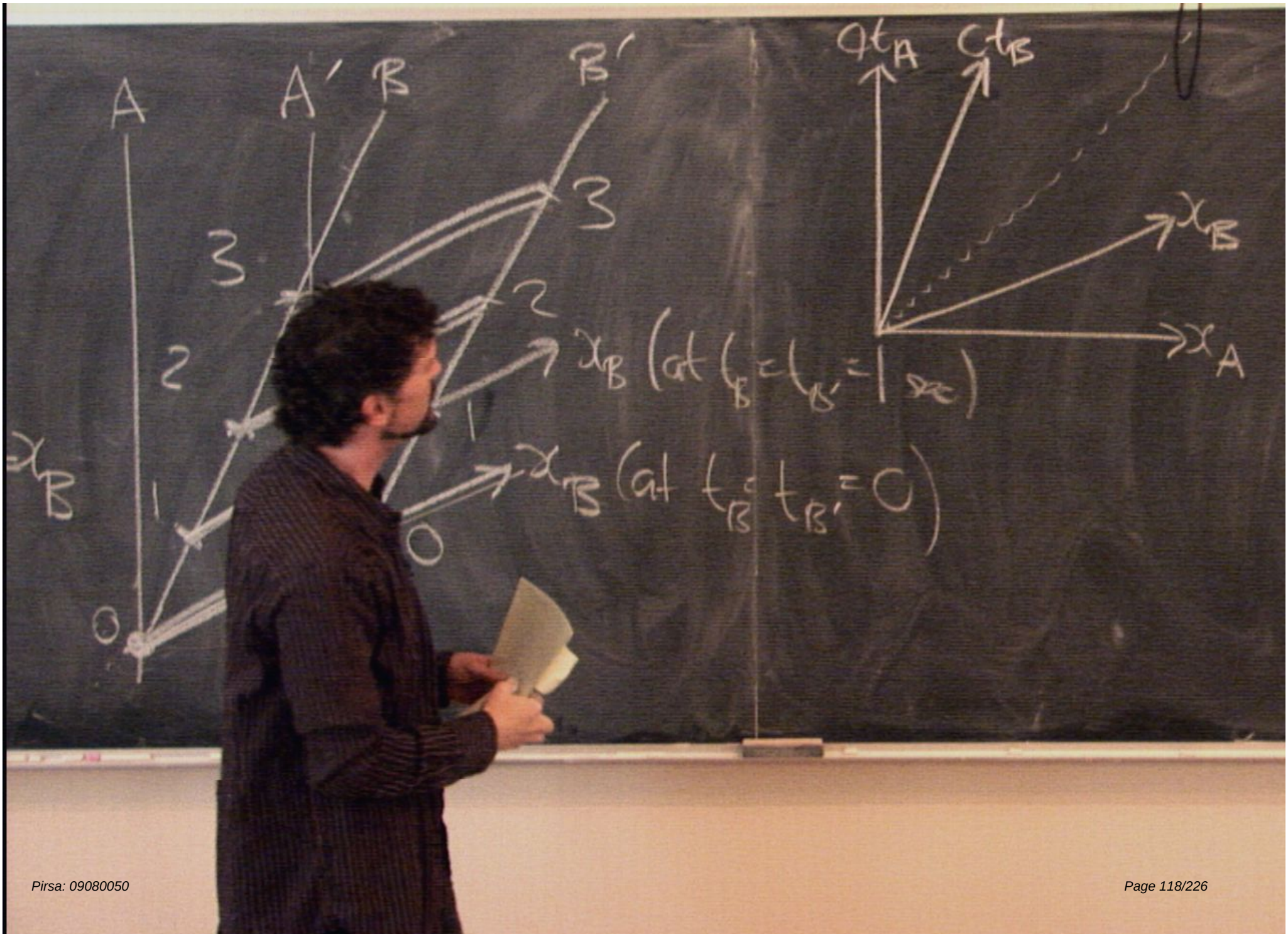
Bdy's x - axis

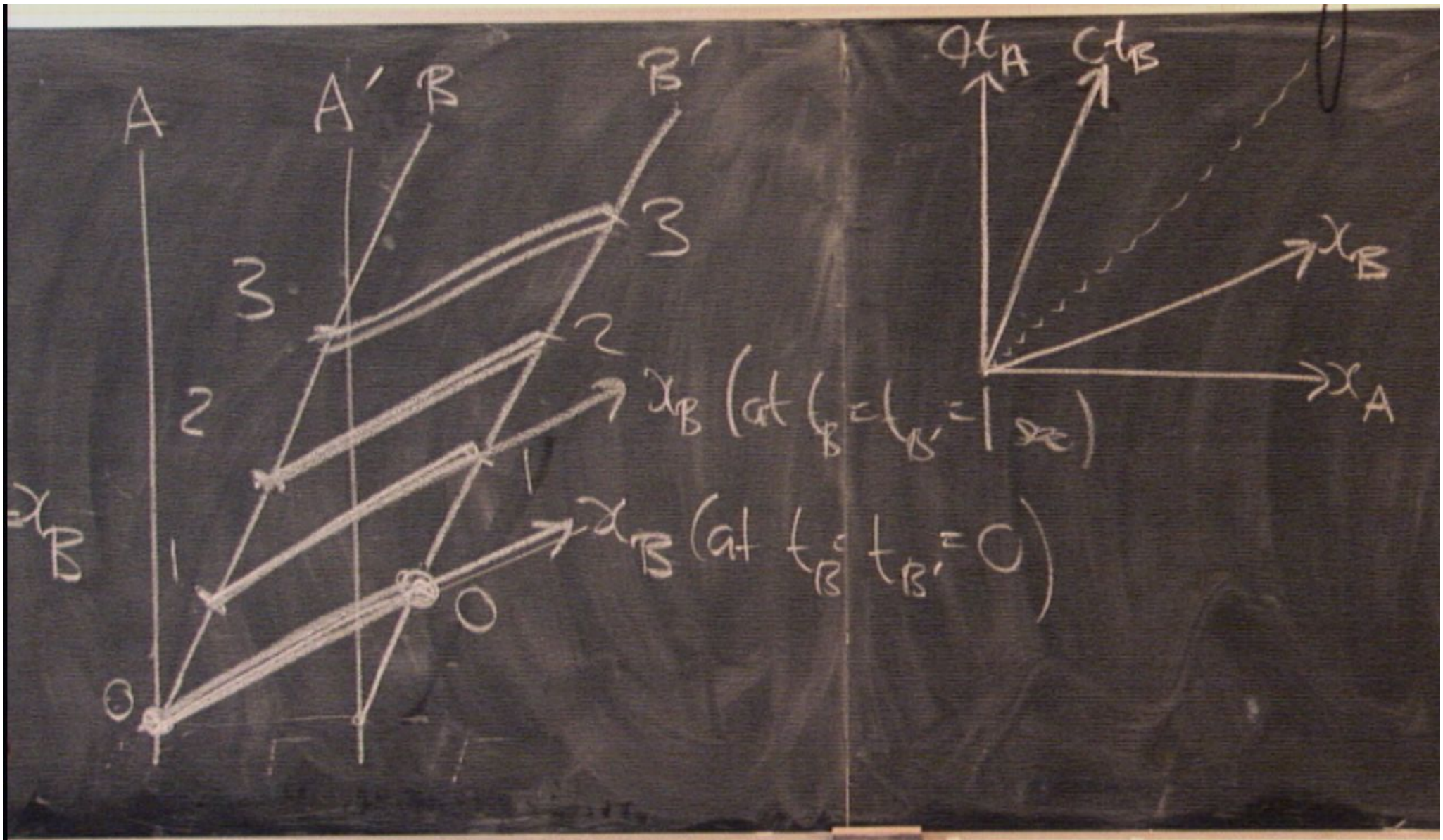


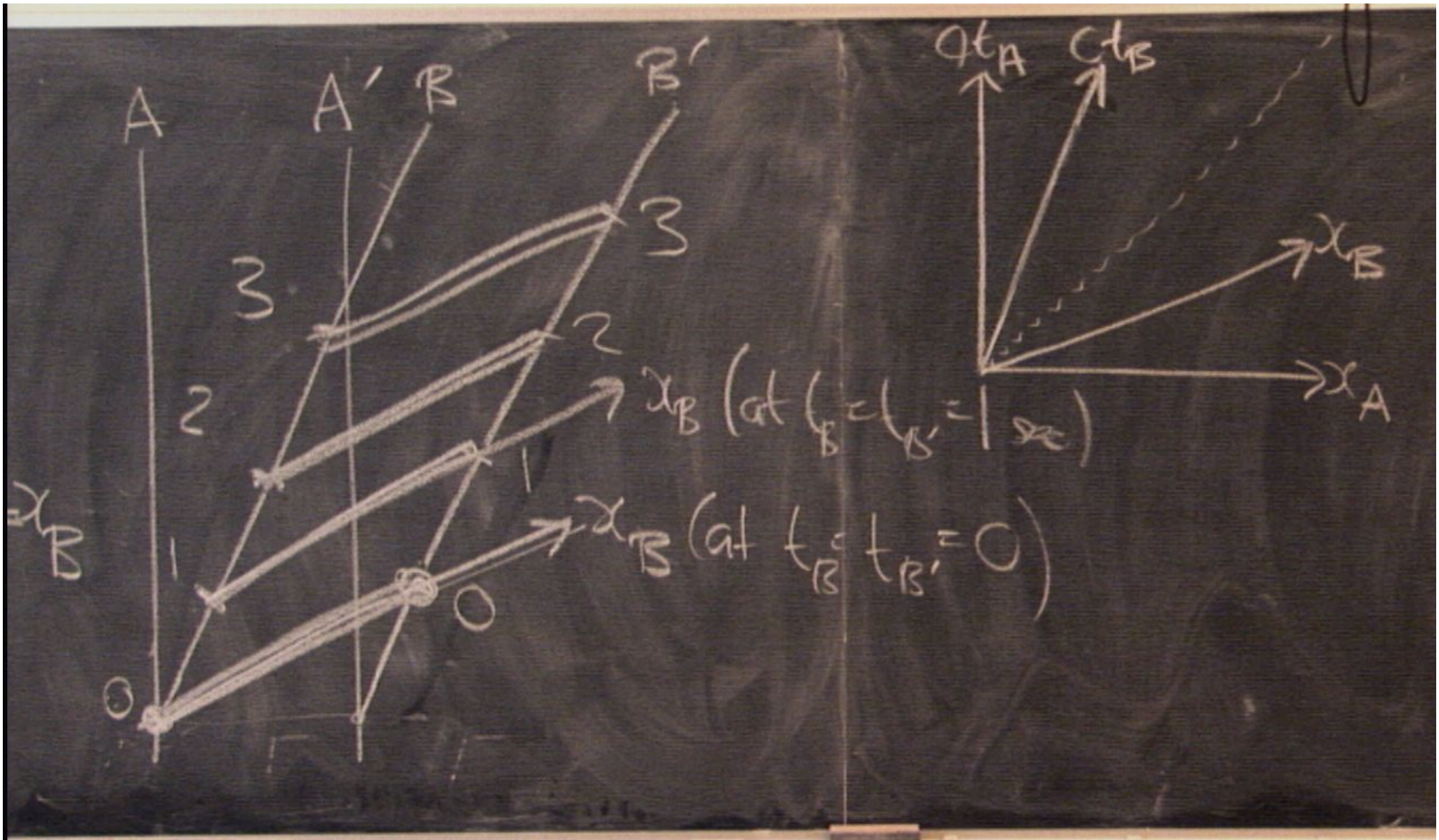


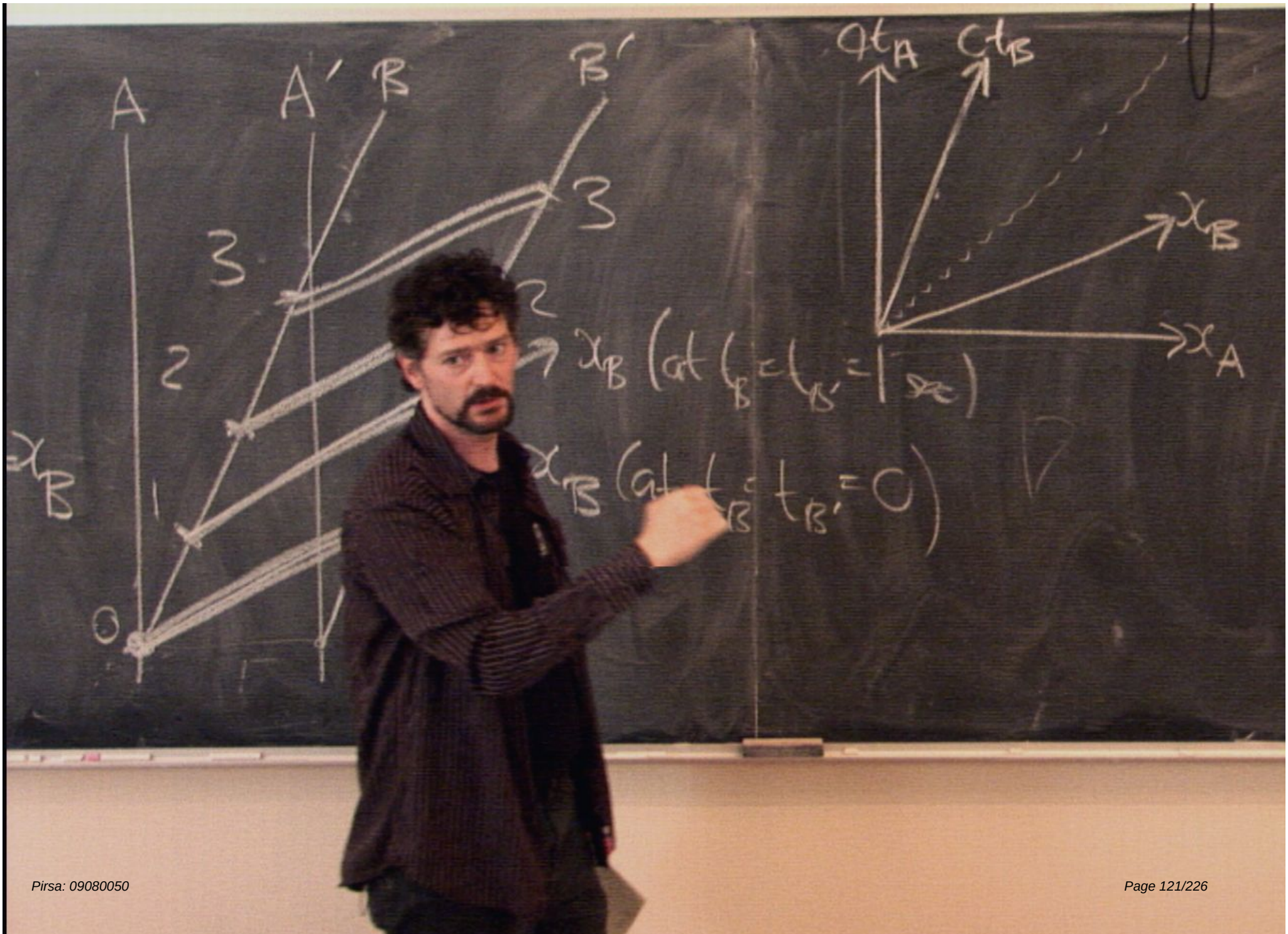

A
A'
B
B'
3
3
2
1
0
x_B
ct_A
ct_B
x_A
(at $t_B = t_{B'} = 1$ sec)
(at $t_B = t_{B'} = 0$)

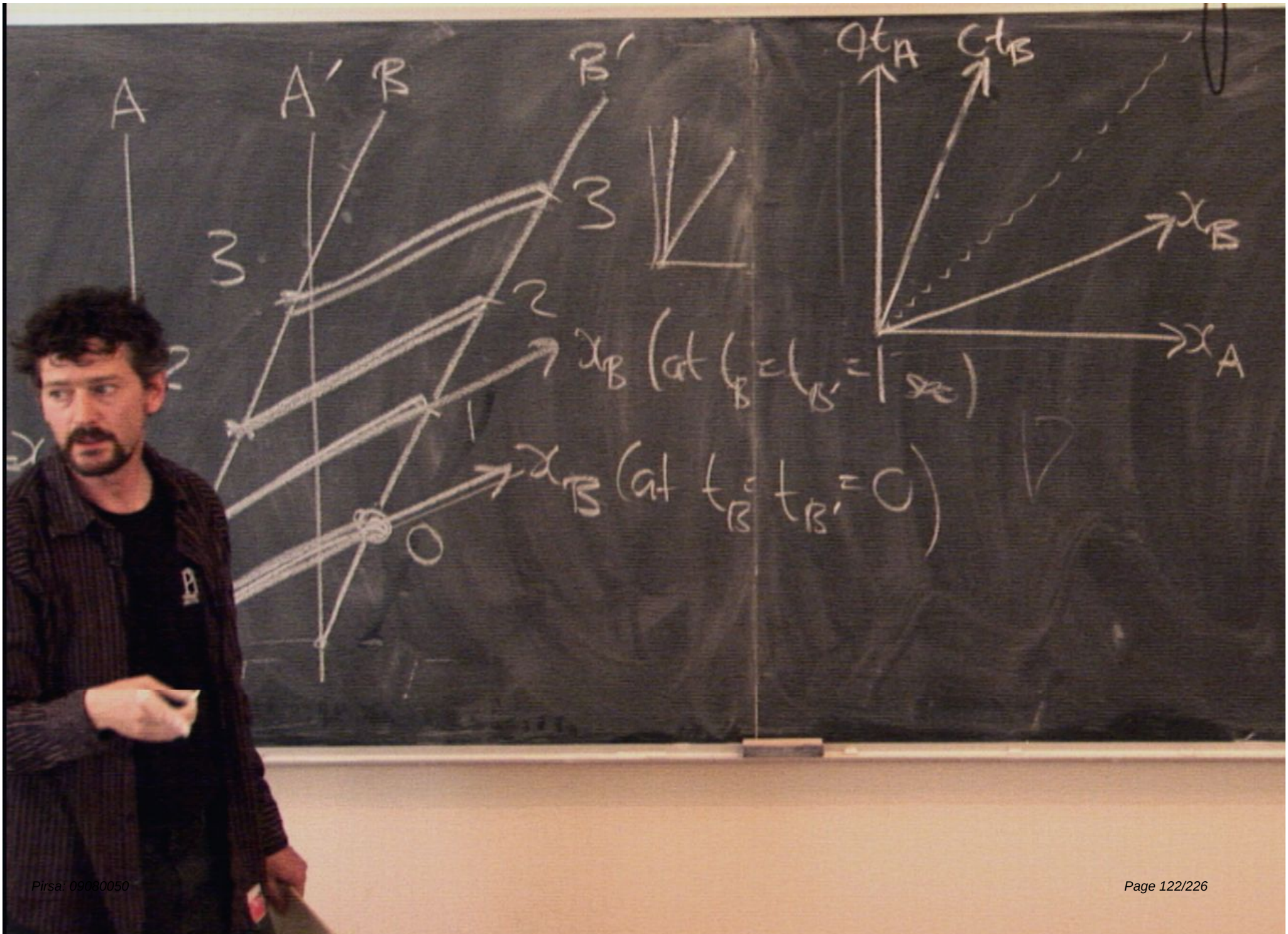

A
A'
B
B'
3
3
2
2
1
0
x_B
x_B (at $t_B = t_{B'} = 1$ sec)
x_B (at $t_B = t_{B'} = 0$)
ct_A
ct_B
x_B
x_A

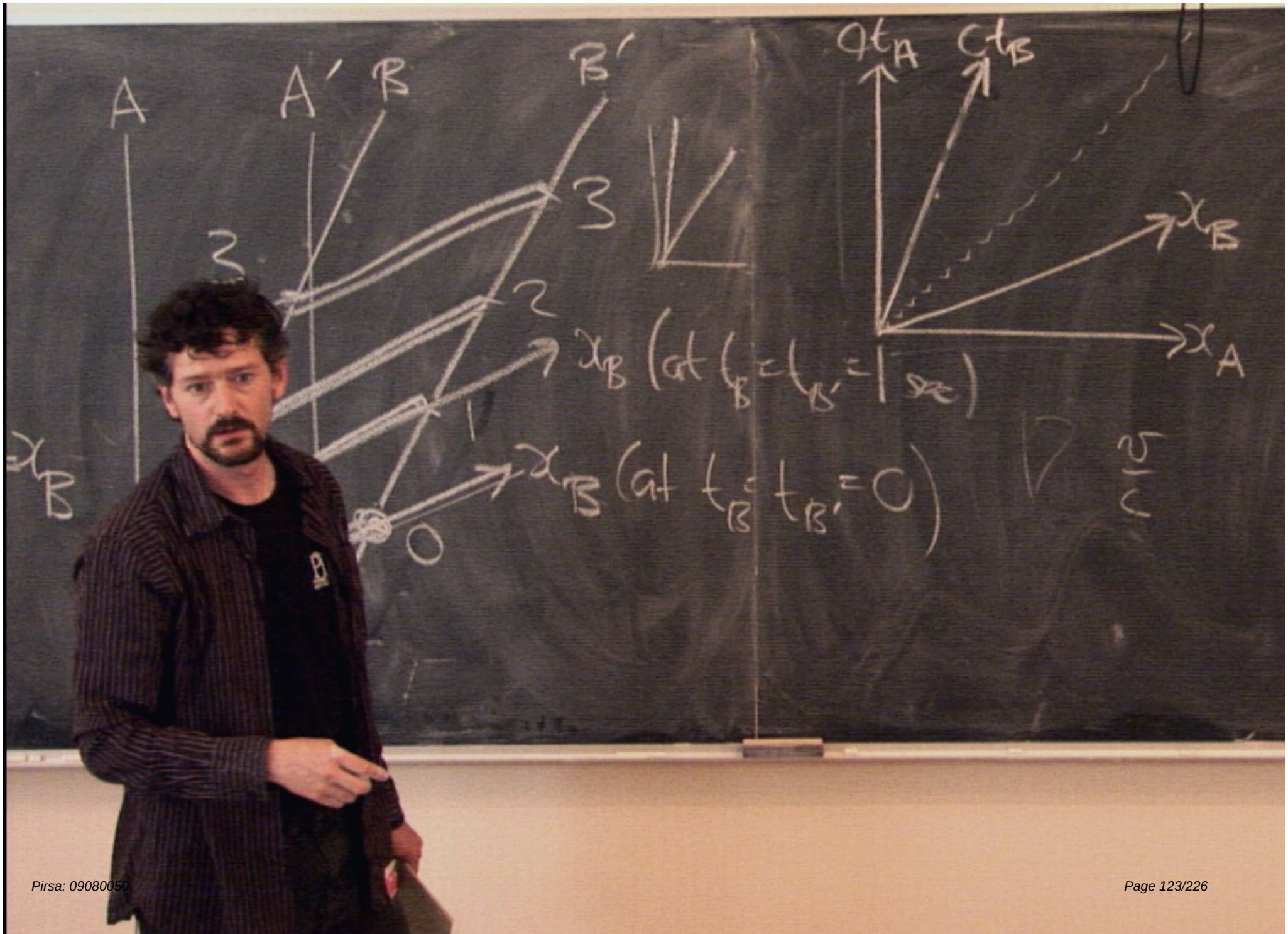

A
A'
B
B'
3
3
2
2
1
1
0
0
x_B
x_B (at $t_B = t_{B'} = 1$ sec)
x_B (at $t_B = t_{B'} = 0$)
ct_A
ct_B
x_B
x_A


A
A'
B
B'
3
3
2
2
1
1
0
0
x_B
x_B (at $t_B = t_{B'} = 1$ sec)
x_B (at $t_B = t_{B'} = 0$)
ct_A
ct_B
x_B
x_A

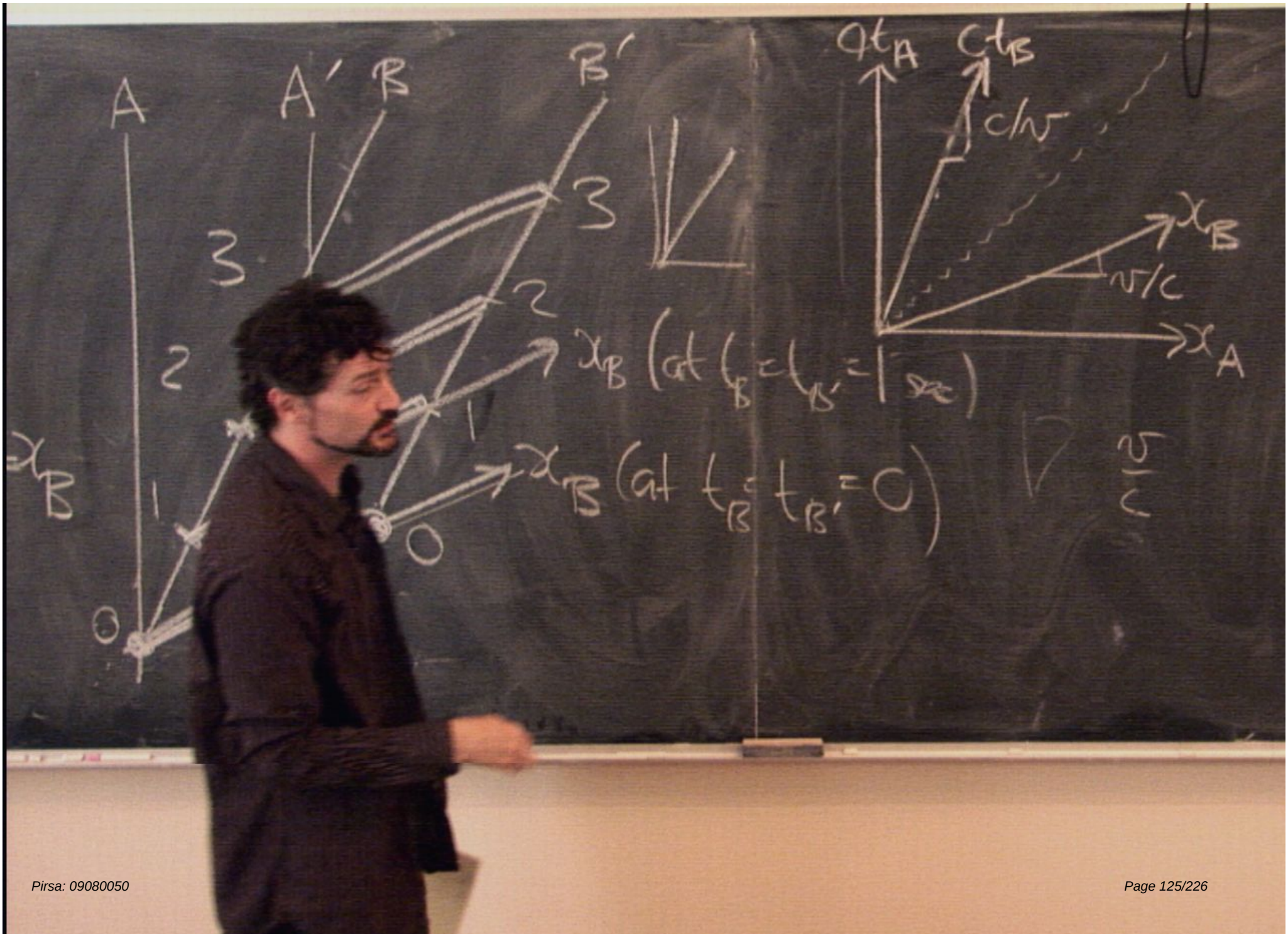

A
A'
B
B'
3
3
2
2
1
1
0
0
x_B
x_B (at $t_B = t_{B'} = 1$ sec)
x_B (at $t_B = t_{B'} = 0$)
ct_A
ct_B
x_B
x_A

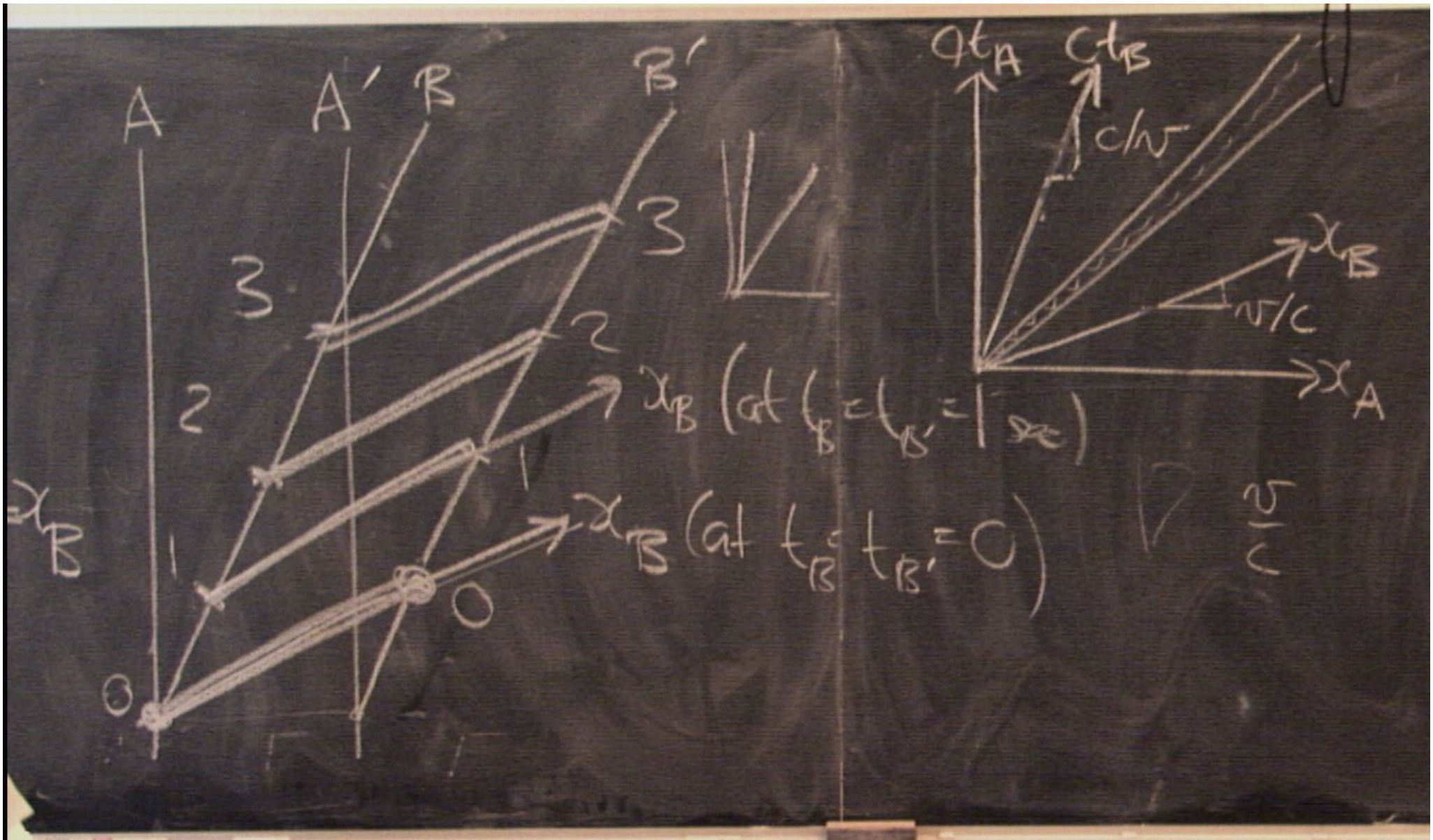

A
A'
B
B'
3
3
2
2
1
0
x_B
x_B (at $t_B = t_{B'} = 0$)
ct_A
ct_B
x_B
x_A

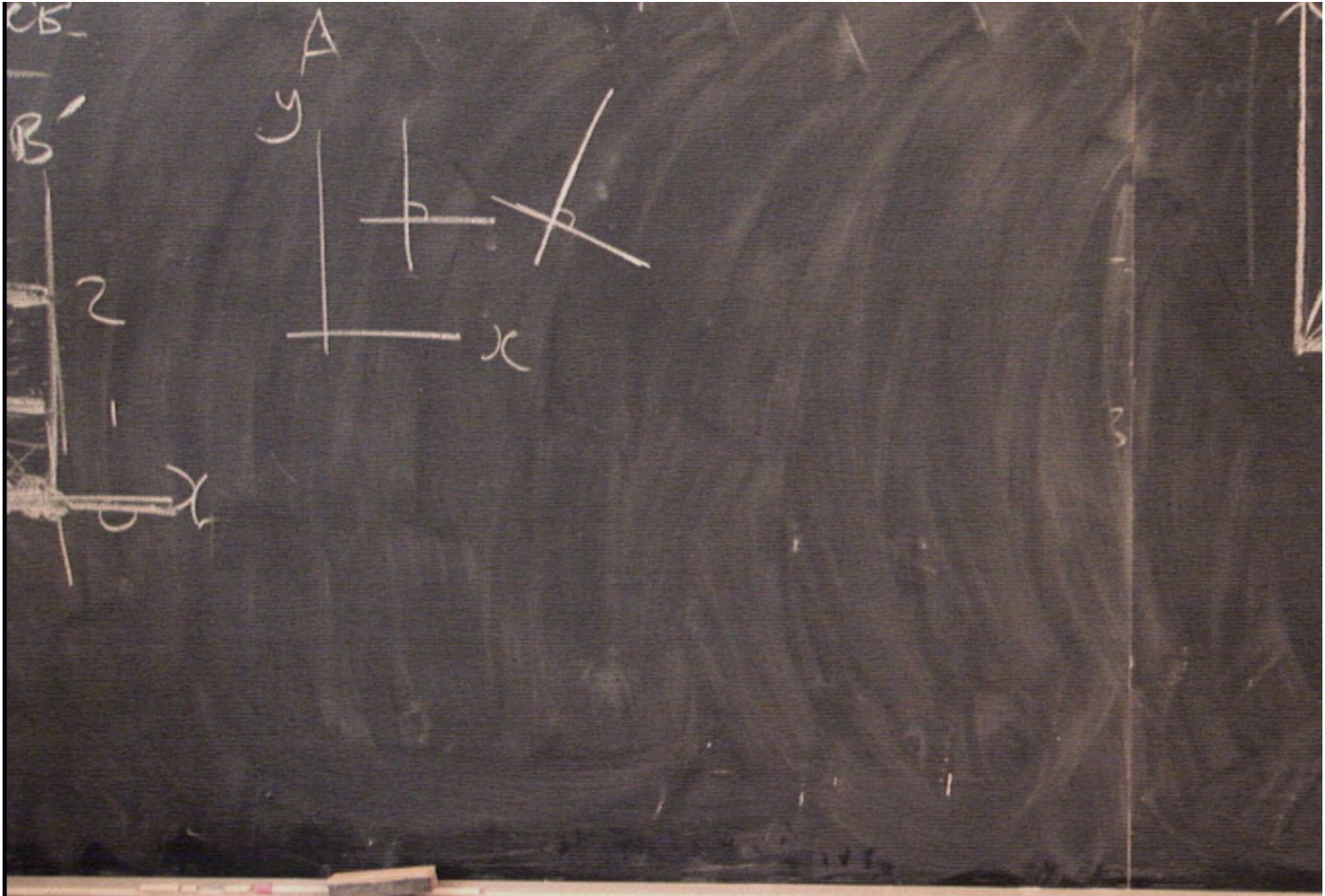

A
A'
B
B'
3
3
2
2
1
0
ct_A
ct_B
x_B
x_A
$x_B\,(ct\,t_B = t_{B'} = 0)$
$x_B\,(ct\,t_B = t_{B'} = 0)$

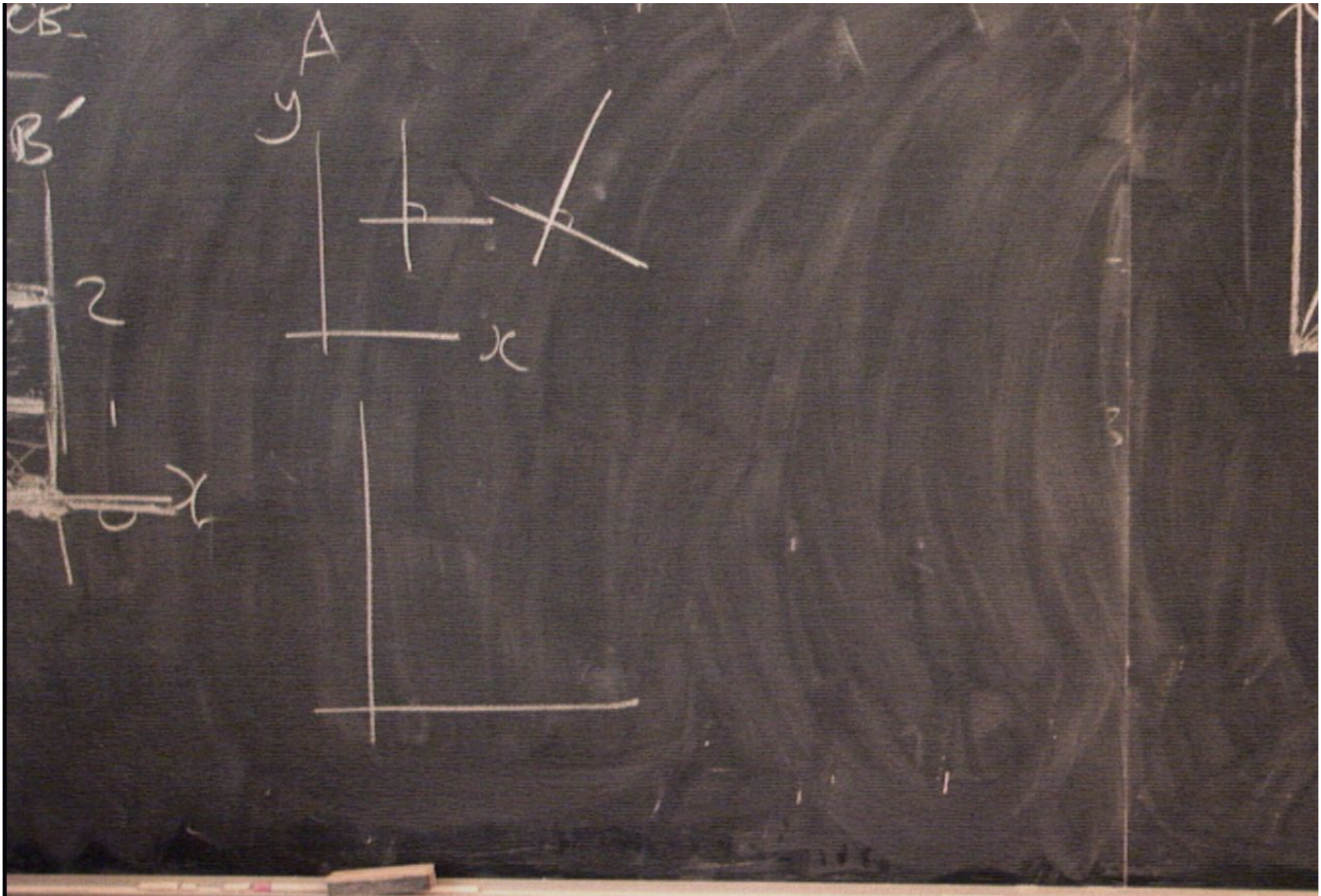

A
A'
B
B'
3
3
2
1
0
x_B
x_B (at $t_B = t_{B'} = 0$)
ct_A
ct_B
x_B
x_A
$\frac{v}{c}$

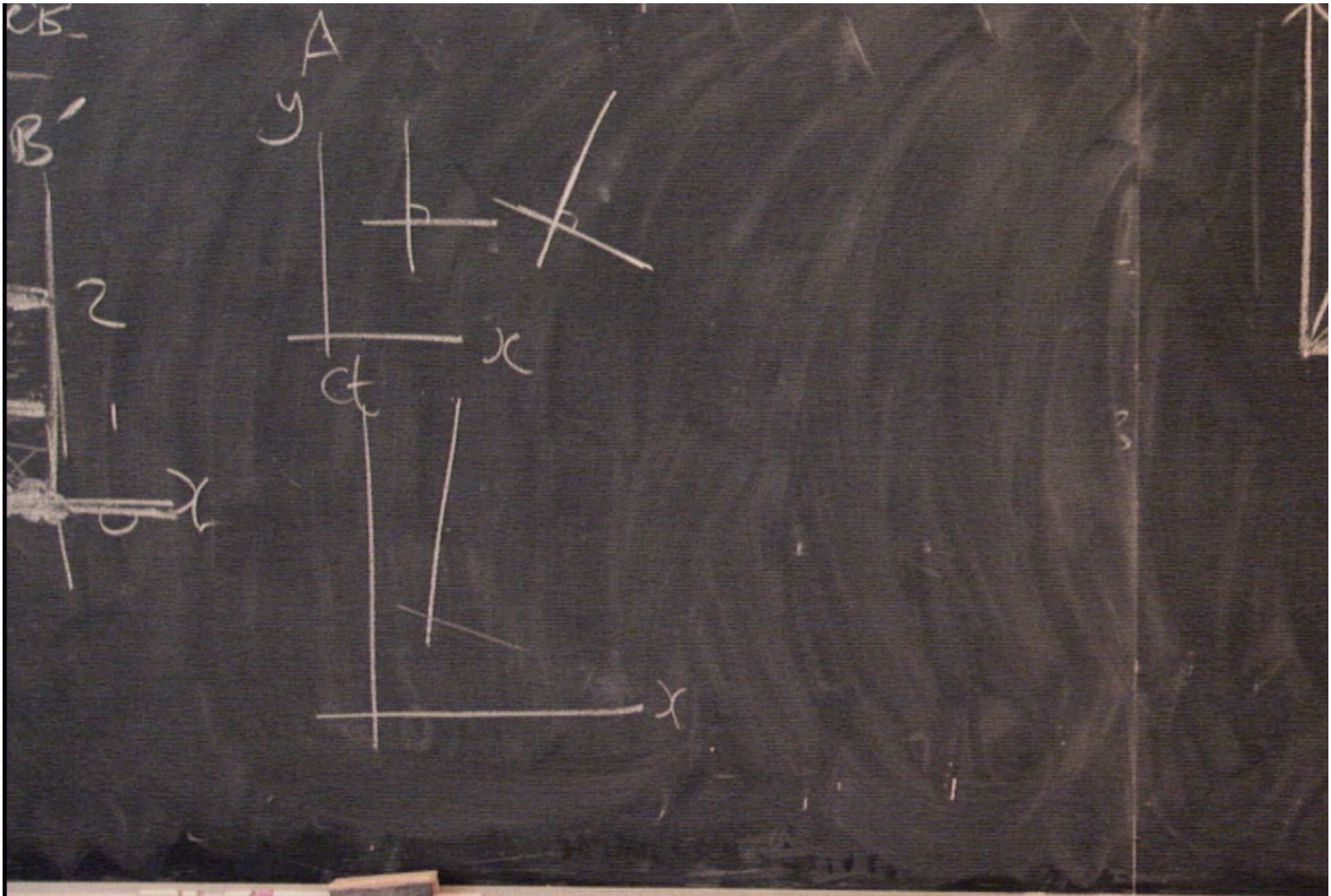

A
A'
B
B'
3
3
2
1
0
x_B
ct_A
ct_B
$ct = x_B$
x_B
x_A
$x_B \; (ct_B = t_{B'} = 0)$
$(ct_B = t_{B'} = 0)$
$\frac{v}{c}$

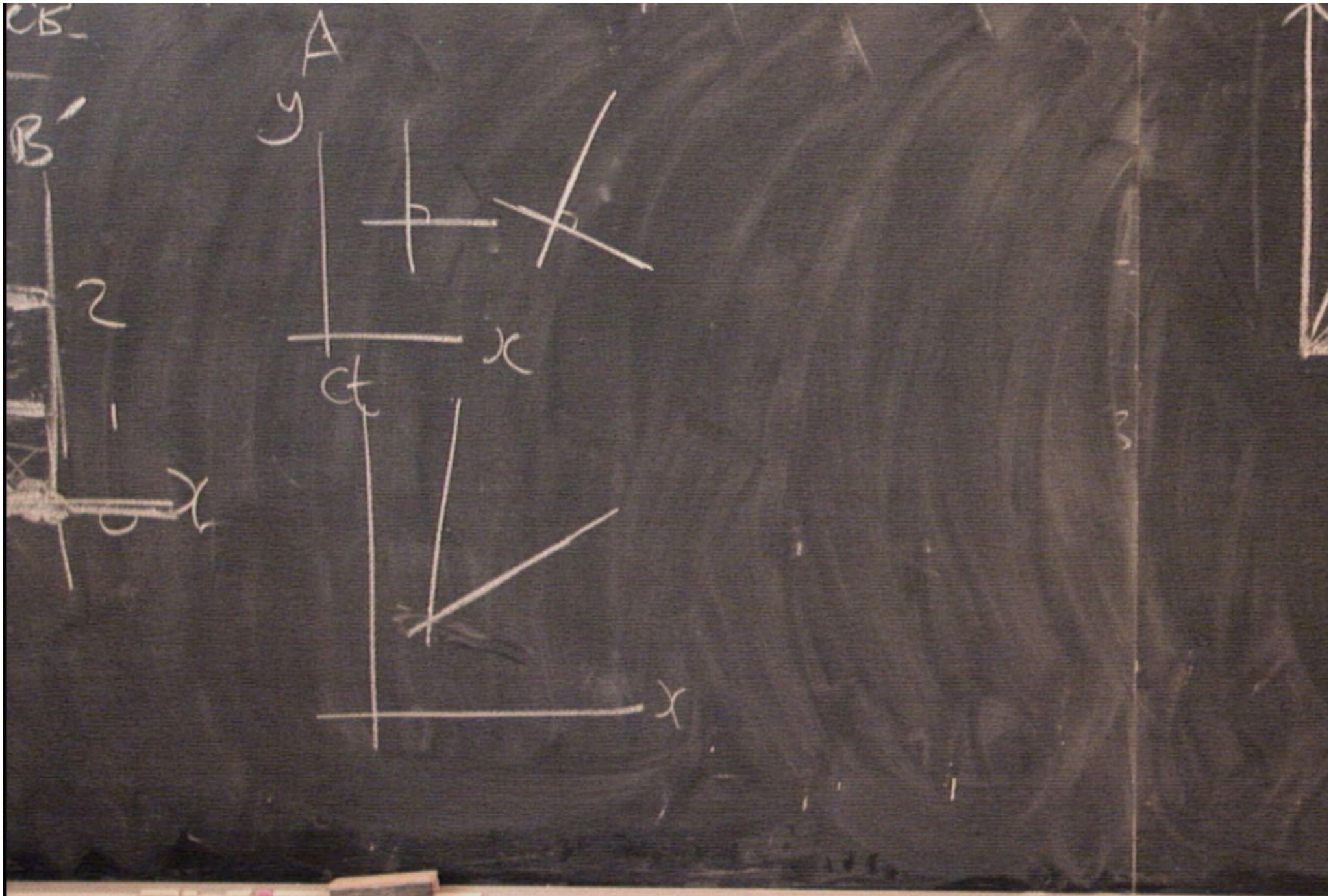

A
A'
B
B'
3
2
1
0
x_B (at $t_B = t_{B'} = 0$)
x_B (at $t_B = t_{B'} = 1$ sec)
ct_A
ct_B
x_B
x_A
v/c
c/v

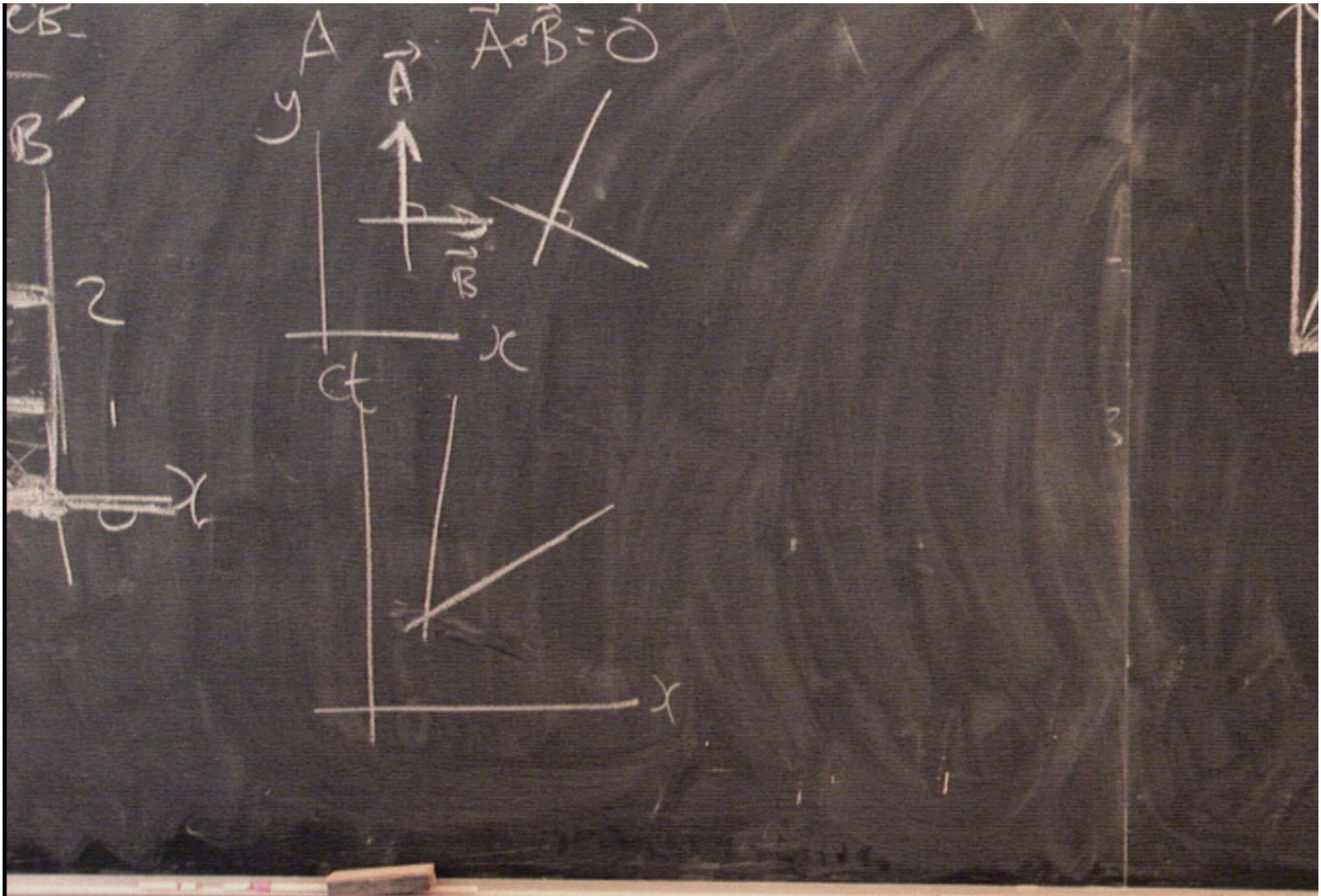

A
A'
B
B'
3
2
1
0
x_B
x_B (at $t_B = t_{B'} = 0$)
x_B (at $t_B = t_{B'}$)
ct_A
ct_B
$ct_{B'}$
x_B
x_A
v/c
v/c

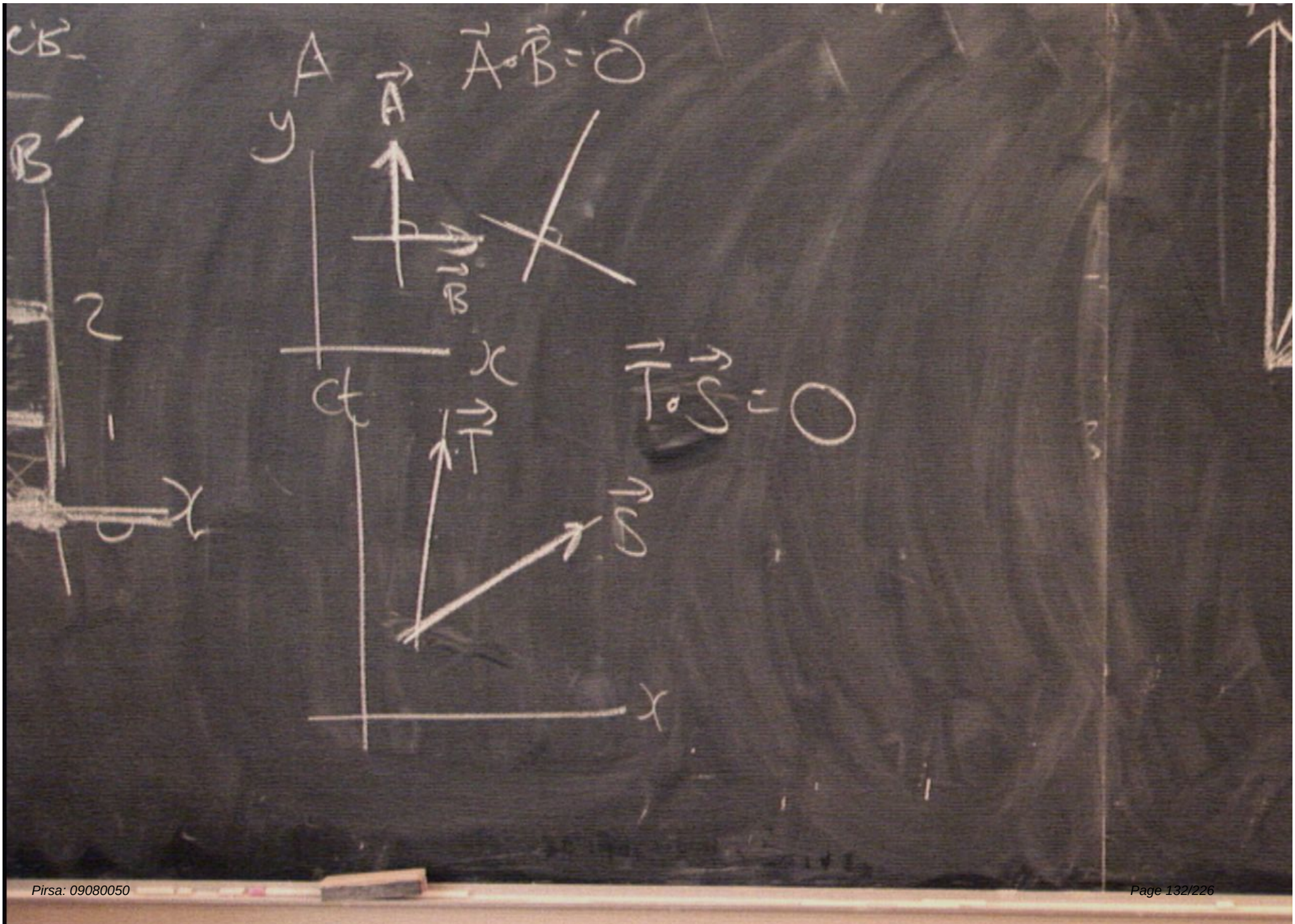

A
y
x
B'
2
1
0
x

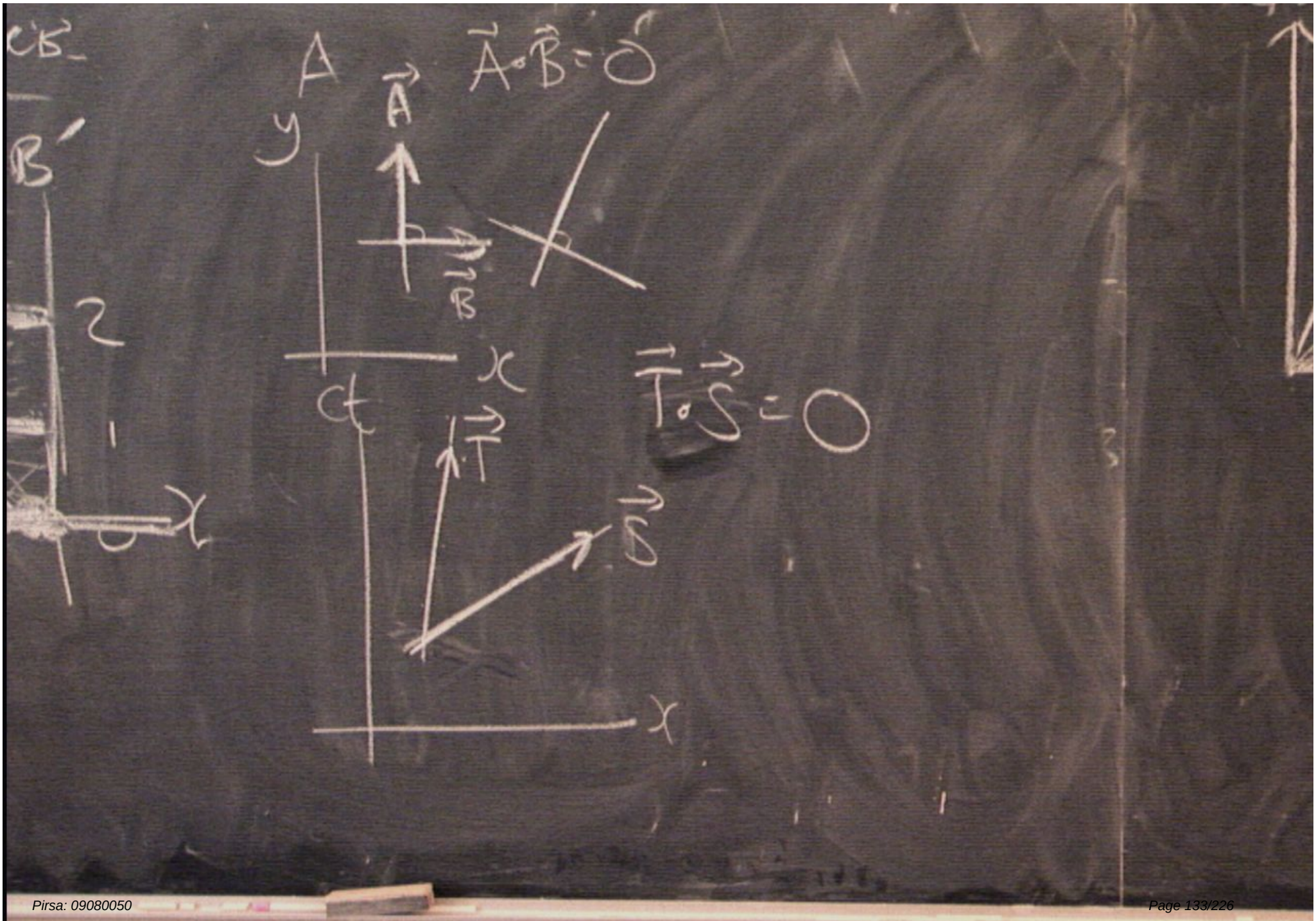

A
y
x
B'
2
1
O
x

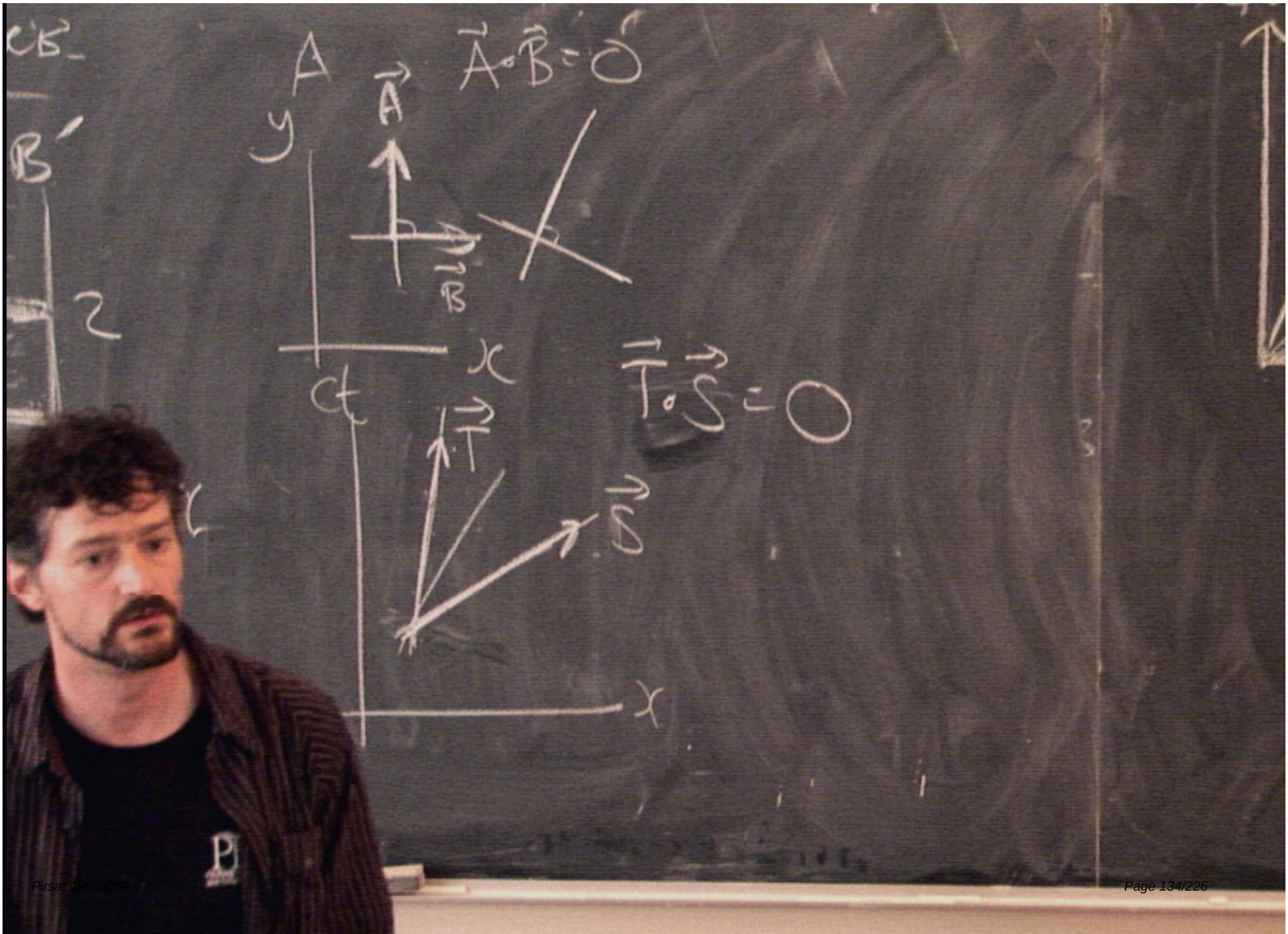

A
y
B'
2
1
x
x
x

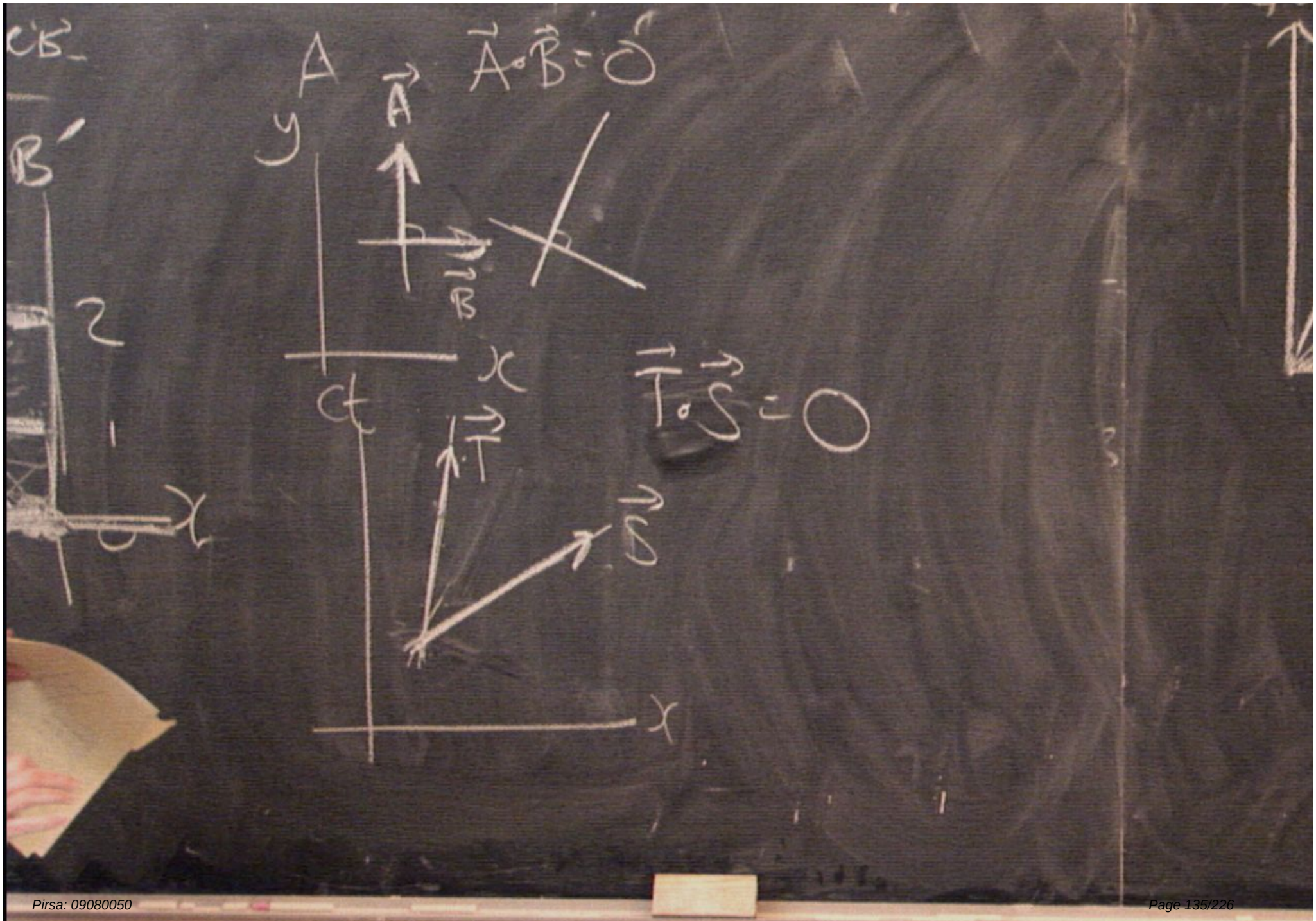

A
y
x
ct
x
B'
2
1
3

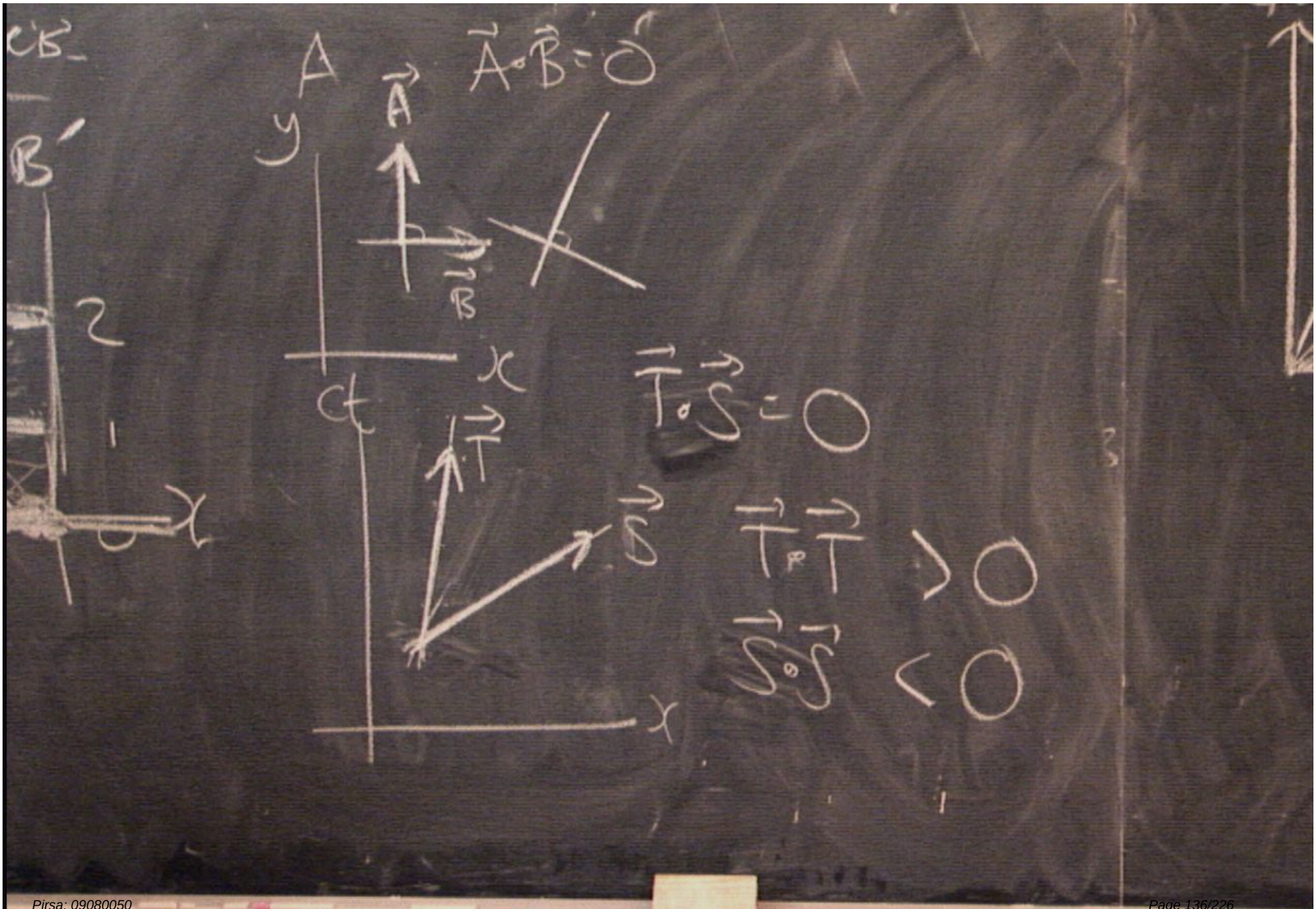

A
$\vec{A} \cdot \vec{B} = 0$
$\vec{A}$
y
$\vec{B}$
x
B'
2
1
x
ct
x

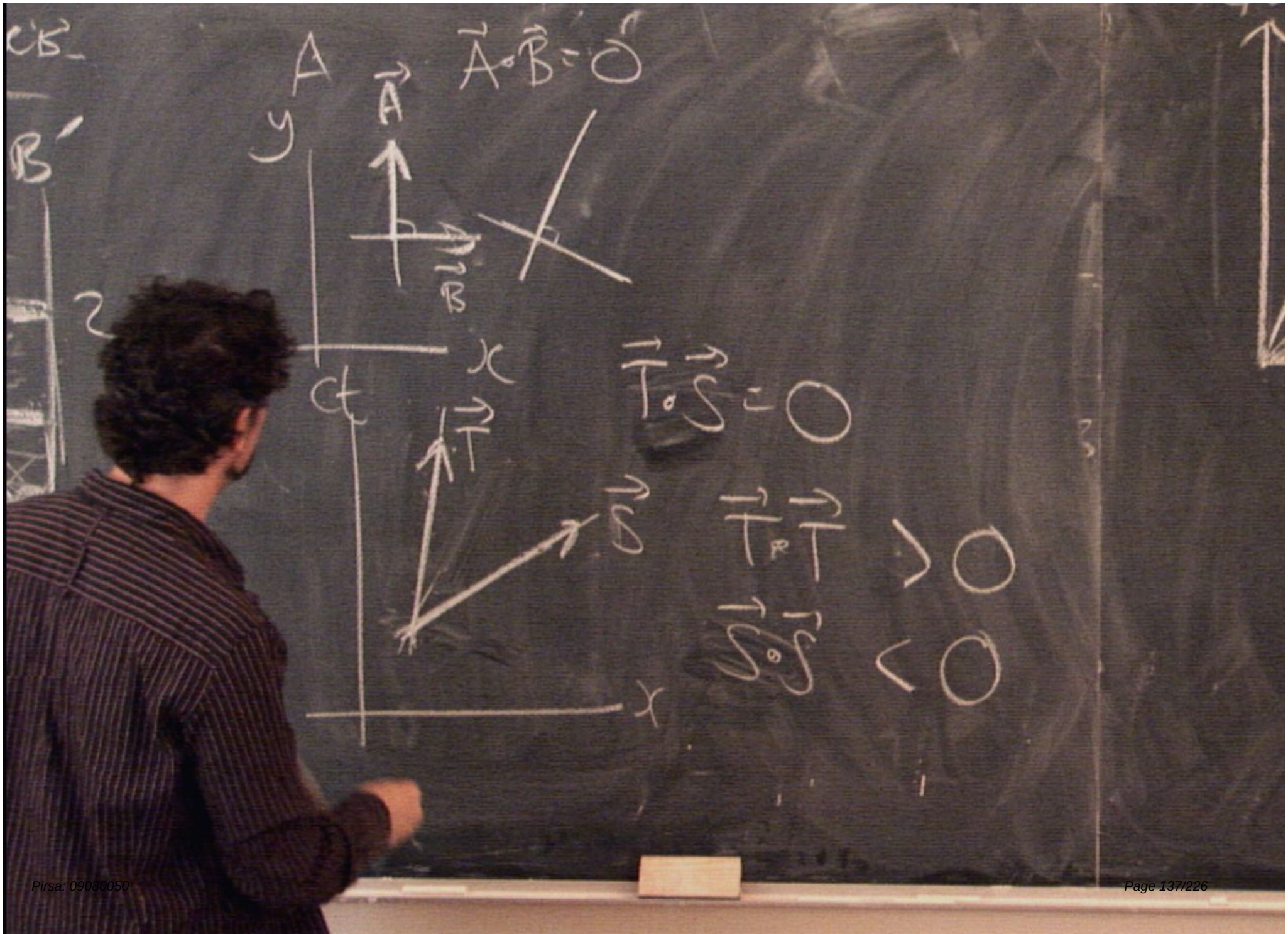

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
$\vec{T} \cdot \vec{S} = 0$
$\vec{T}$
$\vec{S}$
x

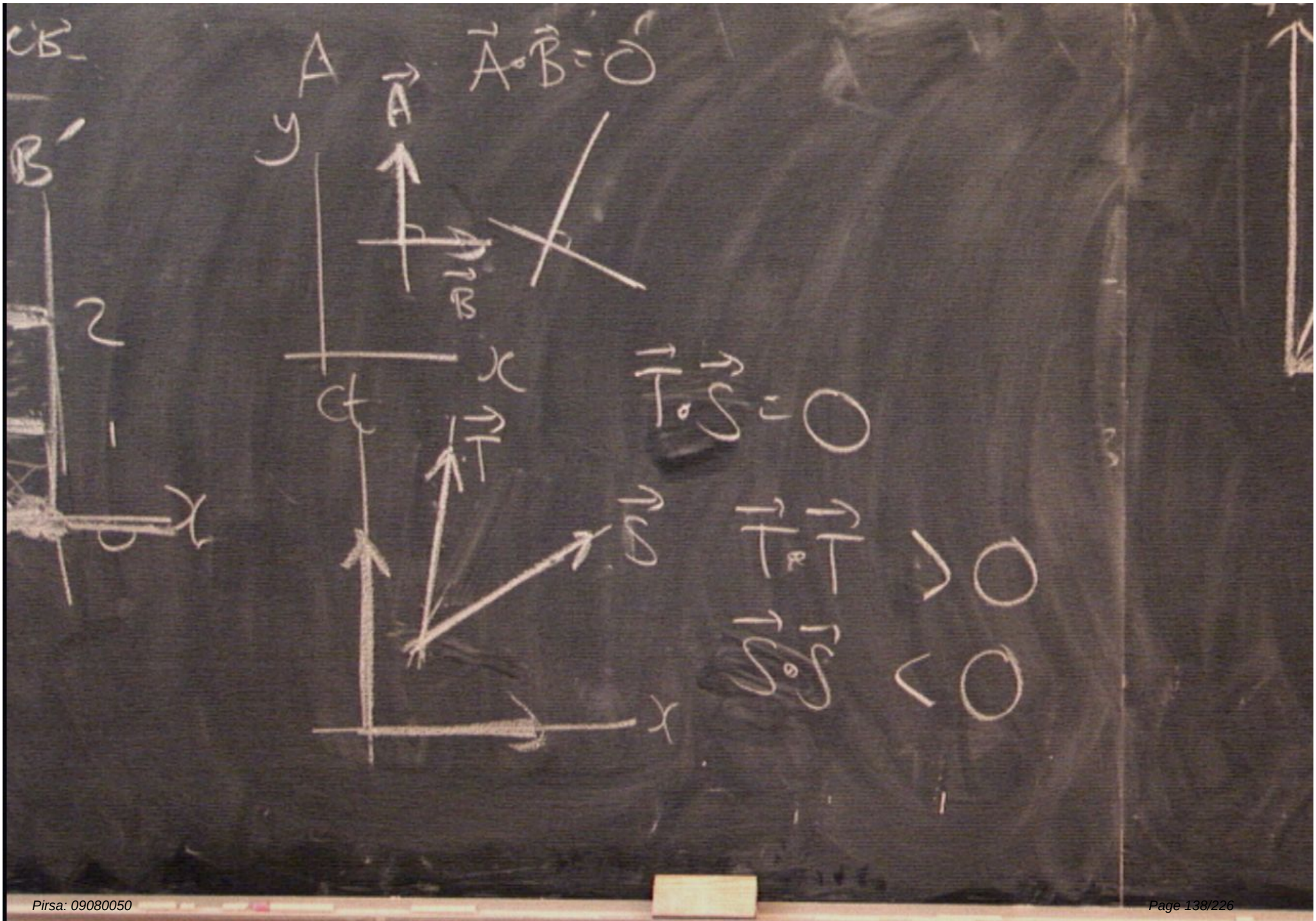

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
$\vec{T} \cdot \vec{S} = 0$
$\vec{T}$
$\vec{S}$
x

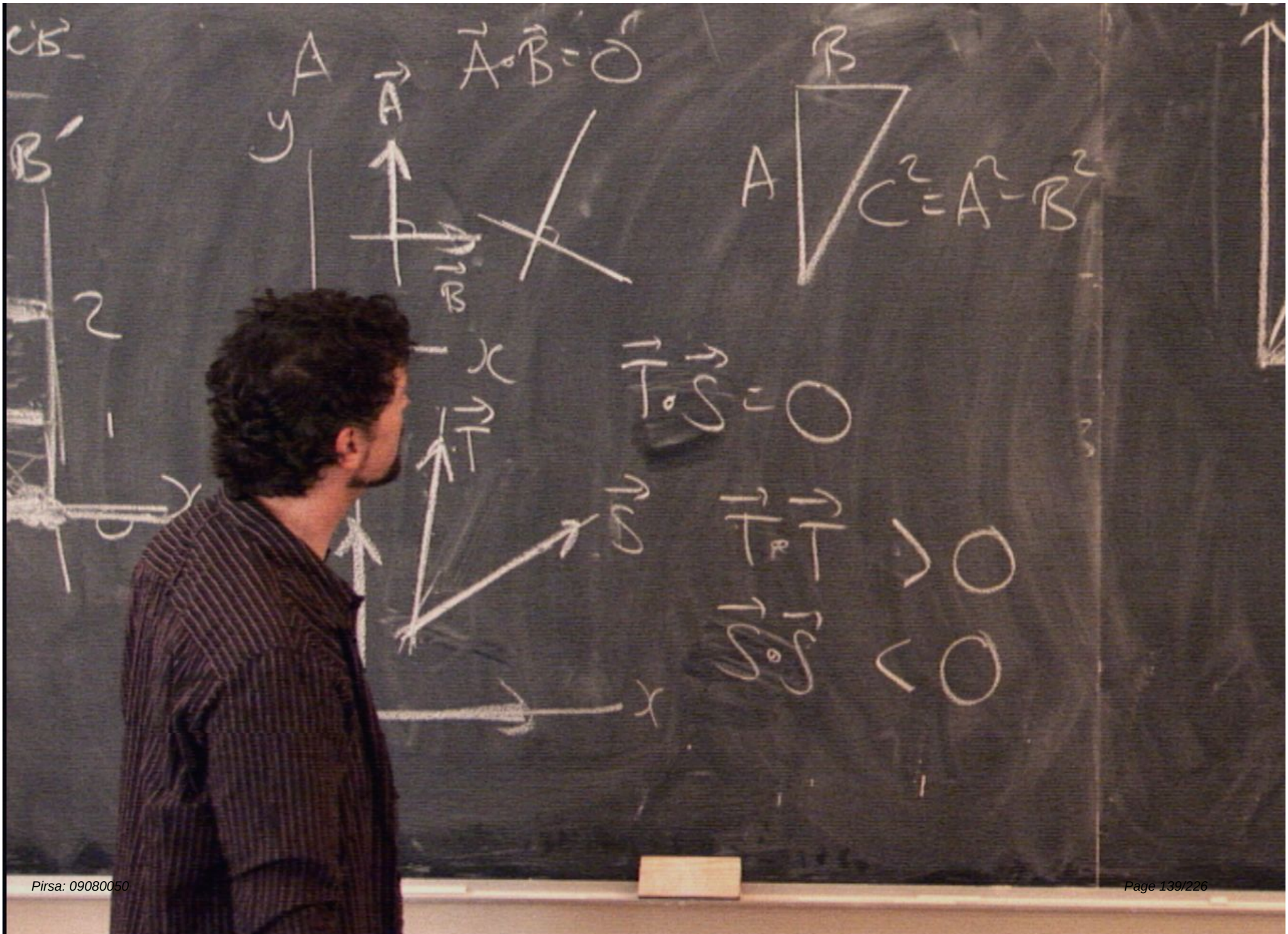

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
$\vec{T} \cdot \vec{S} = 0$
$\vec{T}$
$\vec{S}$
x


A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
$\vec{T} \cdot \vec{S} = 0$
$\vec{T}$
$\vec{S}$
x

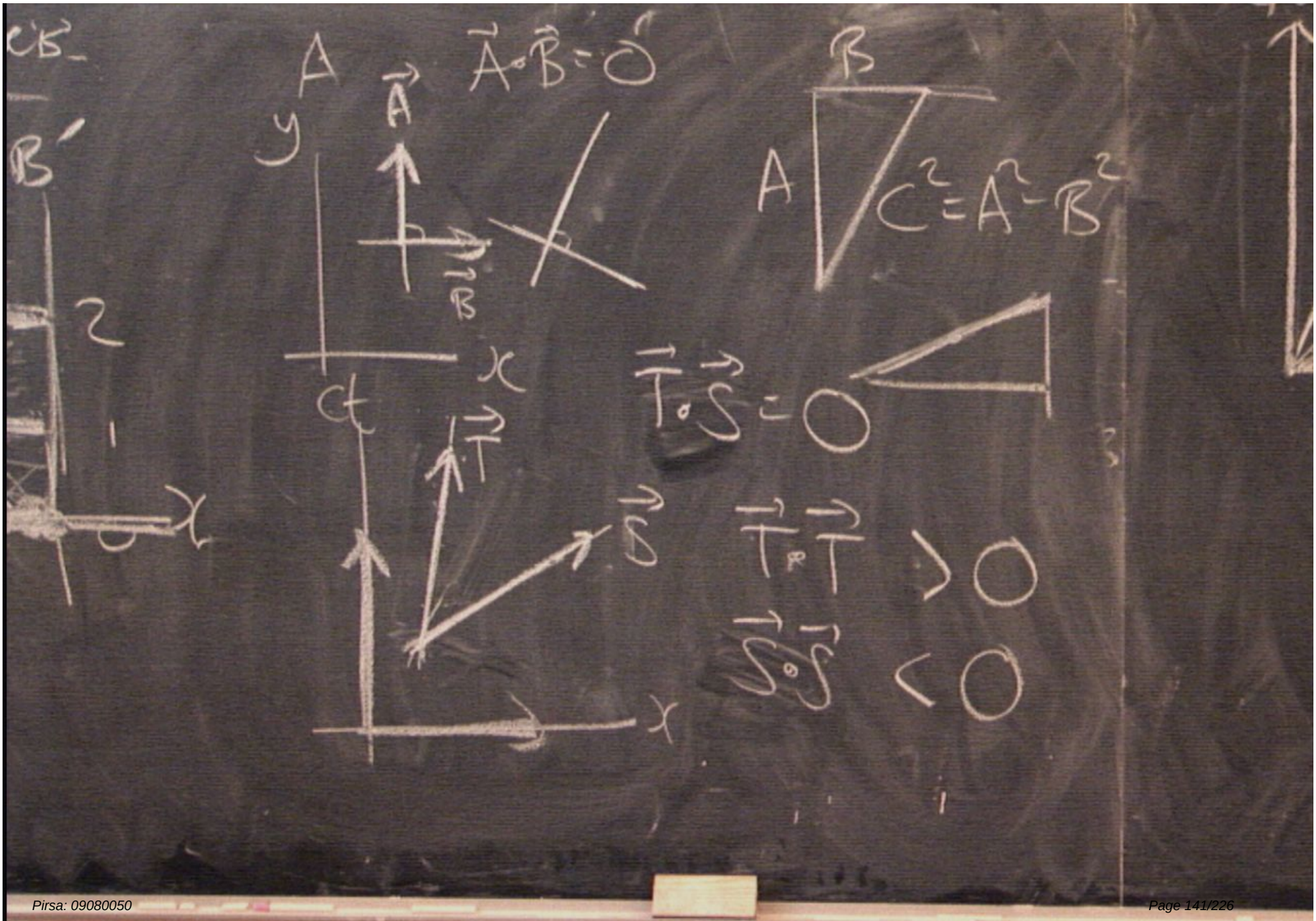

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
$\vec{T} \cdot \vec{S} = 0$
$\vec{T}$
$\vec{S}$
$\vec{T} \cdot \vec{T} > 0$
$\vec{S} \cdot \vec{S} < 0$

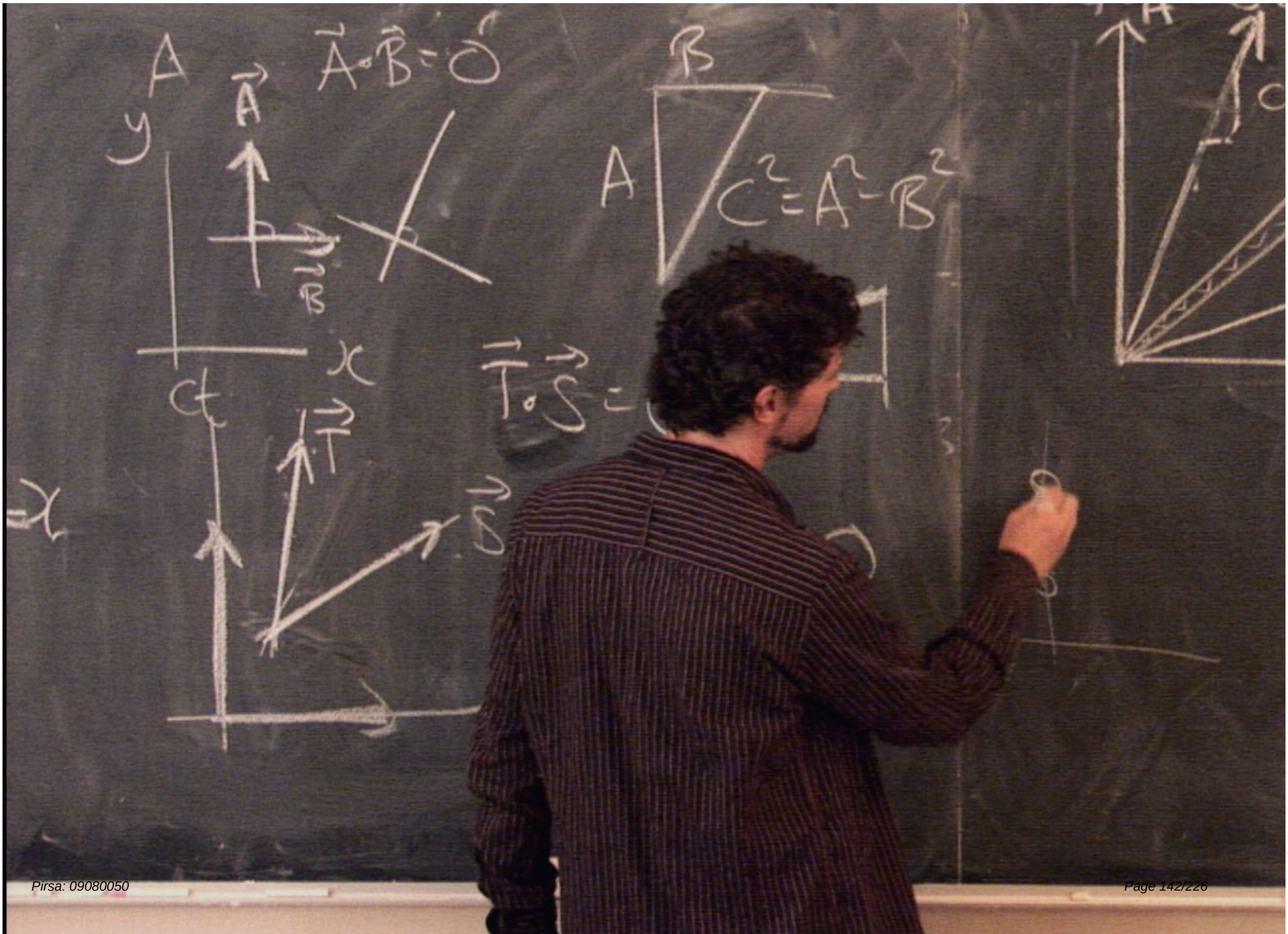

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
z
x
ct
$\vec{T}$
$\vec{S}$
$\vec{T} \cdot \vec{S} = 0$
$\vec{T} \cdot \vec{T} > 0$
$\vec{S} \cdot \vec{S} < 0$
x

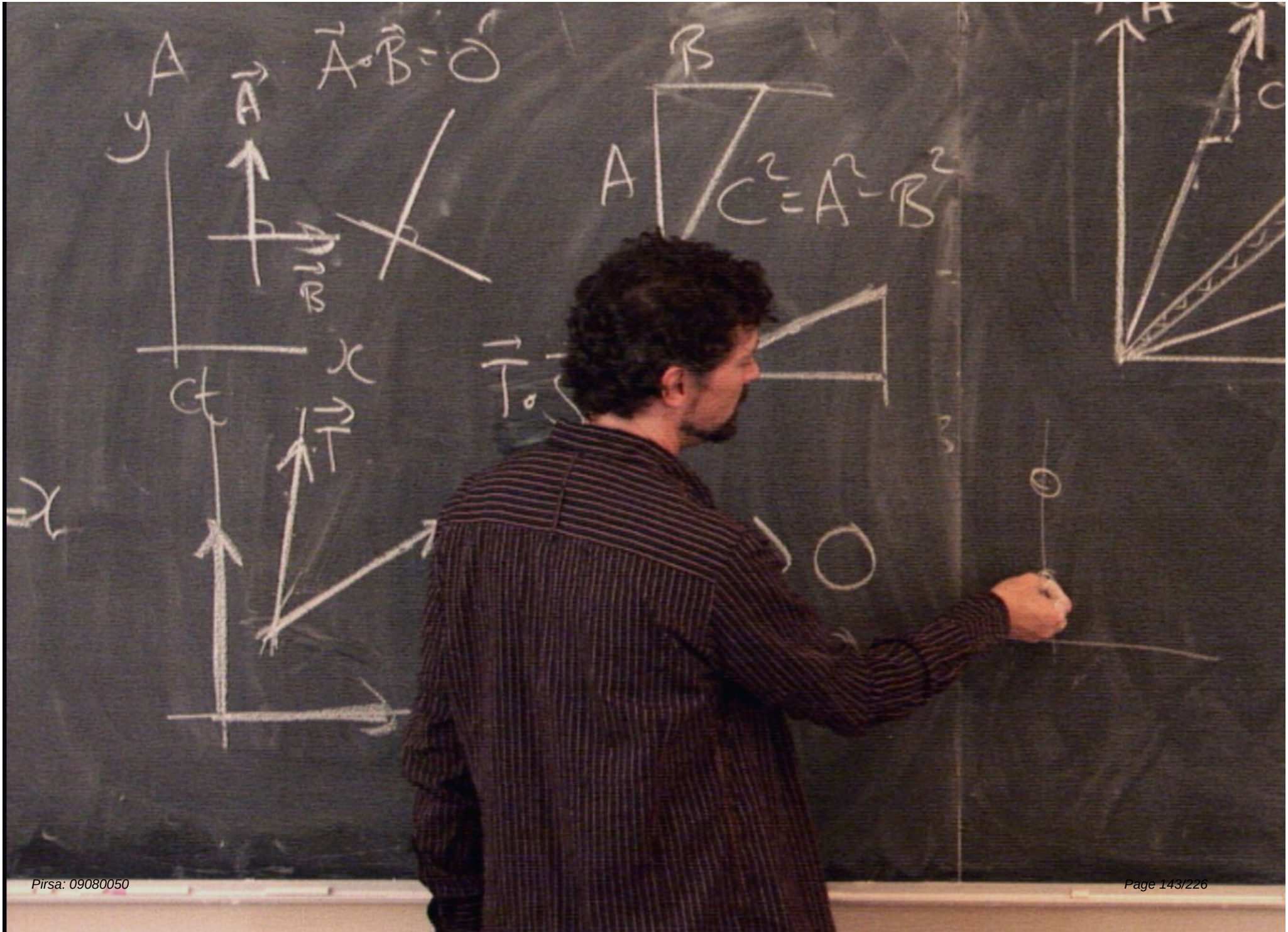

A
$\vec{A}\cdot\vec{B}=0$
y
$\vec{A}$
$\vec{B}$
x
$\vec{T}\cdot\vec{S}=0$
$\vec{T}$
$\vec{S}$
$\vec{T}\cdot\vec{T}>0$
$\vec{S}\cdot\vec{S}<0$

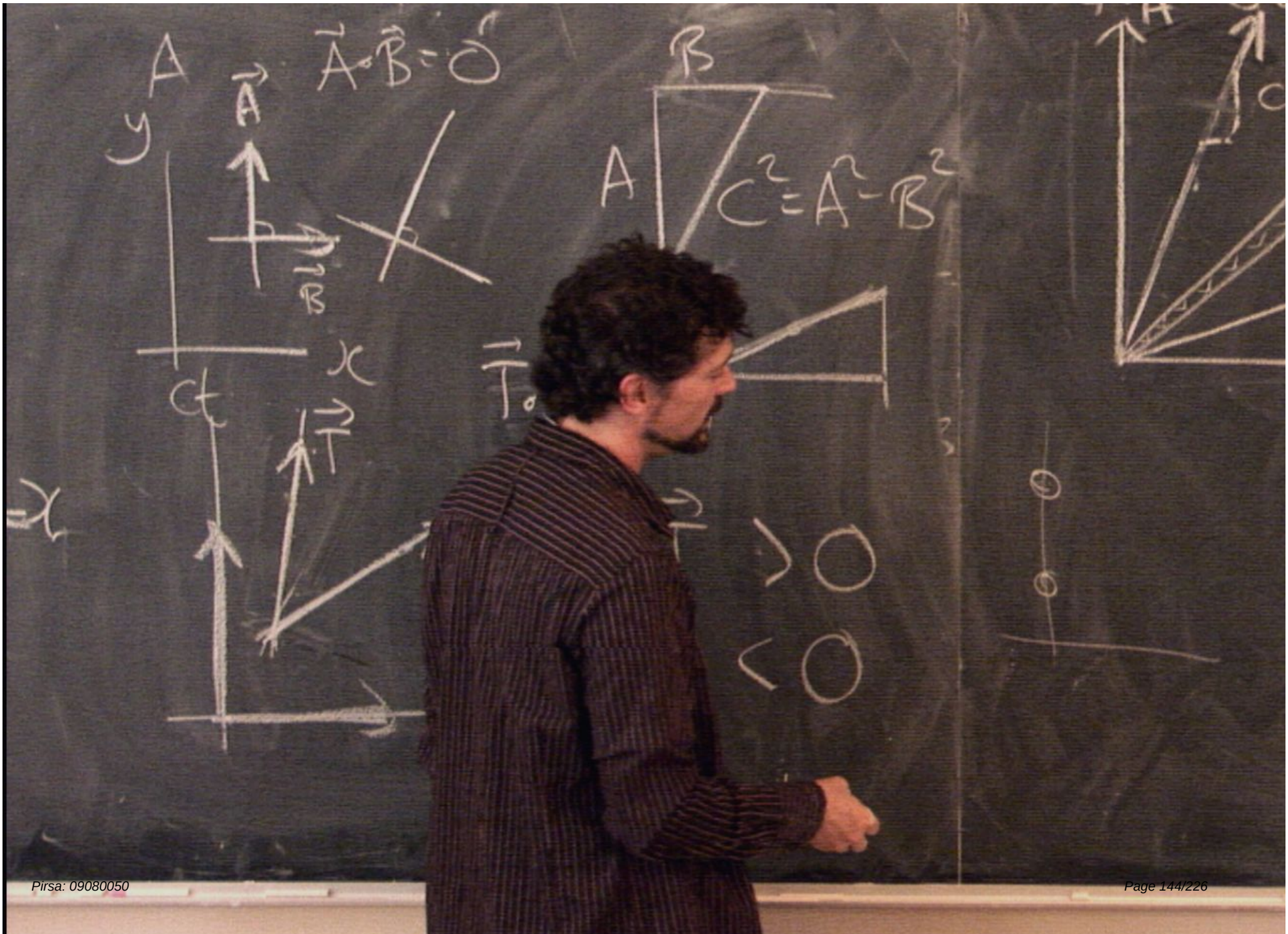

A
$\vec{A}$
$\vec{A}\cdot\vec{B}=0$
B
A
$C^2=A^2-B^2$
y
x
$\vec{T}\cdot\vec{S}=0$
$\vec{T}\cdot\vec{T}>0$
$\vec{S}\cdot\vec{S}<0$

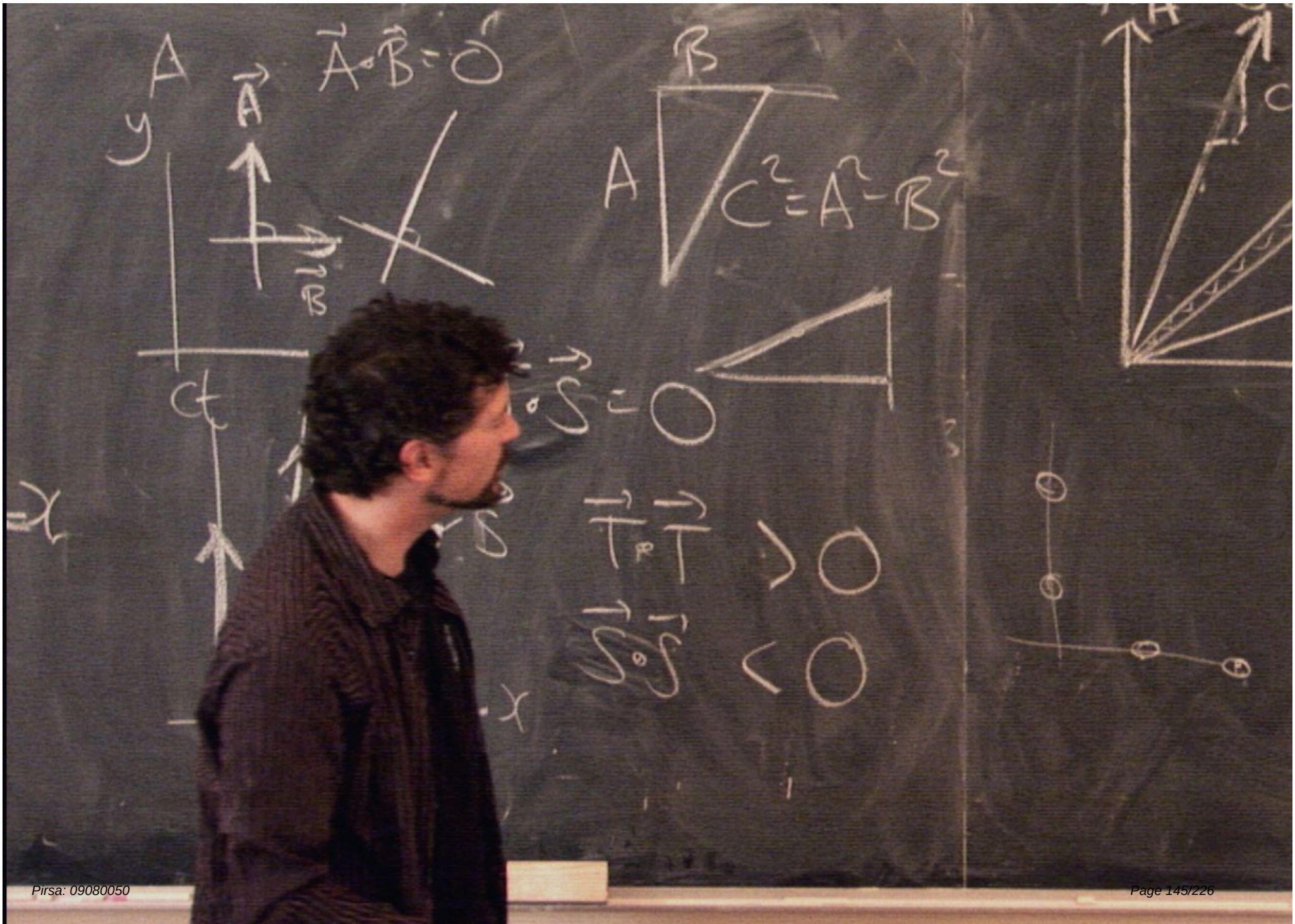

A
$\vec{A}\cdot\vec{B}=0$
B
$C^2=A^2-B^2$
$\vec{S}=0$
$\vec{T}$
>0
<0

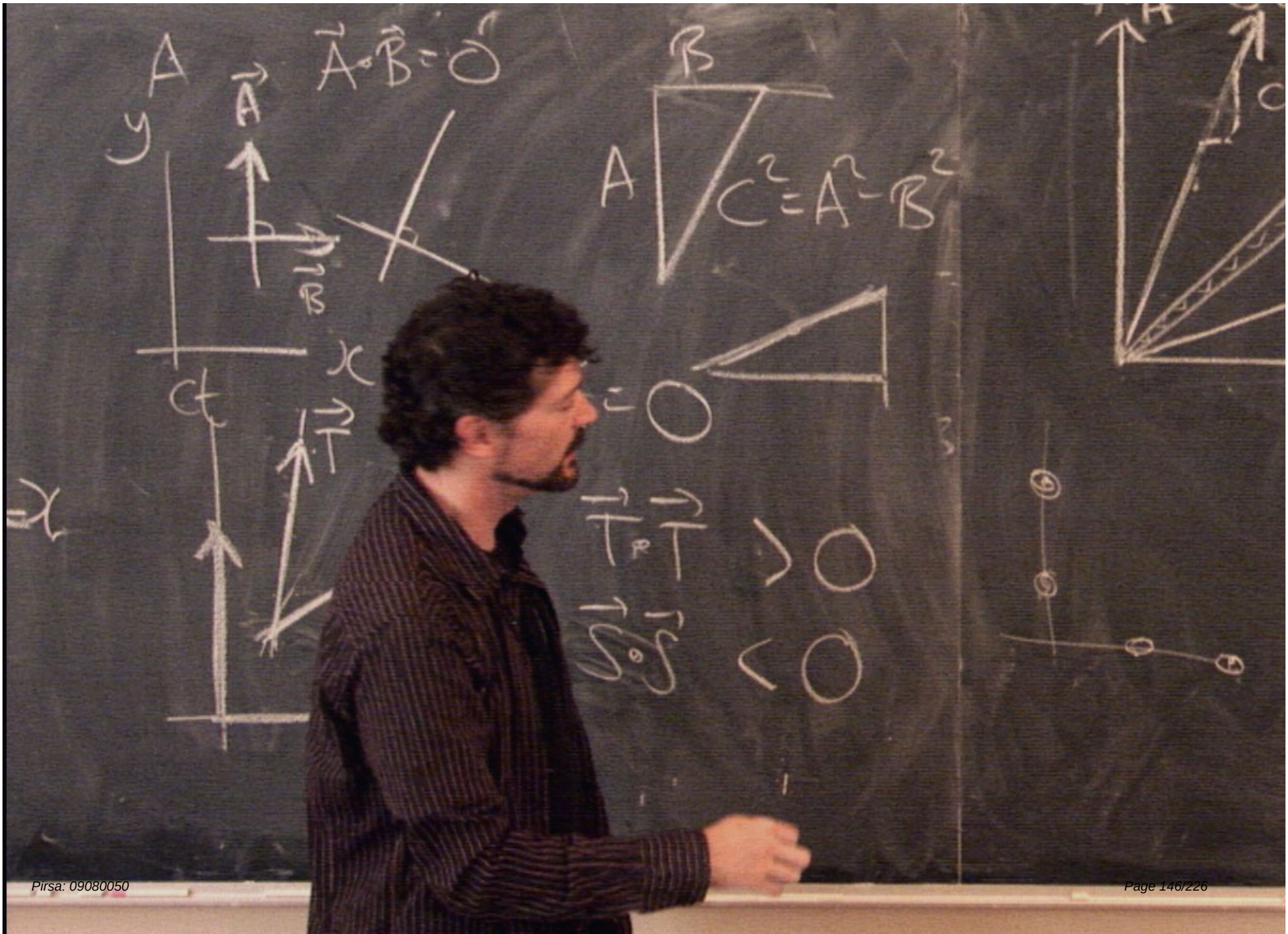

A
$\vec{A}\cdot\vec{B}=0$
B
$C^2=A^2-B^2$
$\vec{T}\cdot\vec{S}=0$
$\vec{T}\cdot\vec{T}>0$
$\vec{S}\cdot\vec{S}<0$

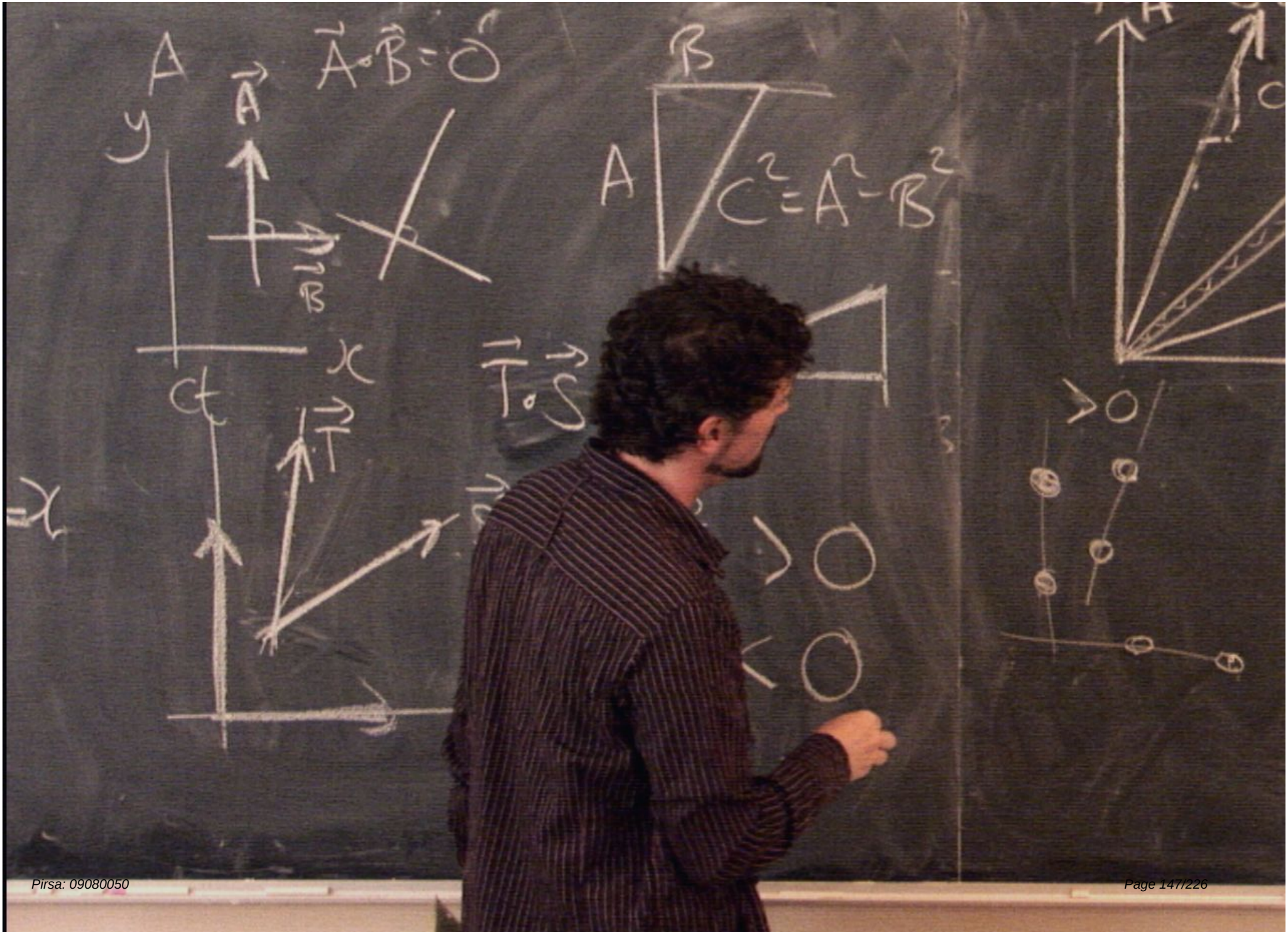

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
B
A
$C^2 = A^2 - B^2$
$\vec{T} \cdot \vec{S} =$
$\vec{T}$
$\vec{S}$

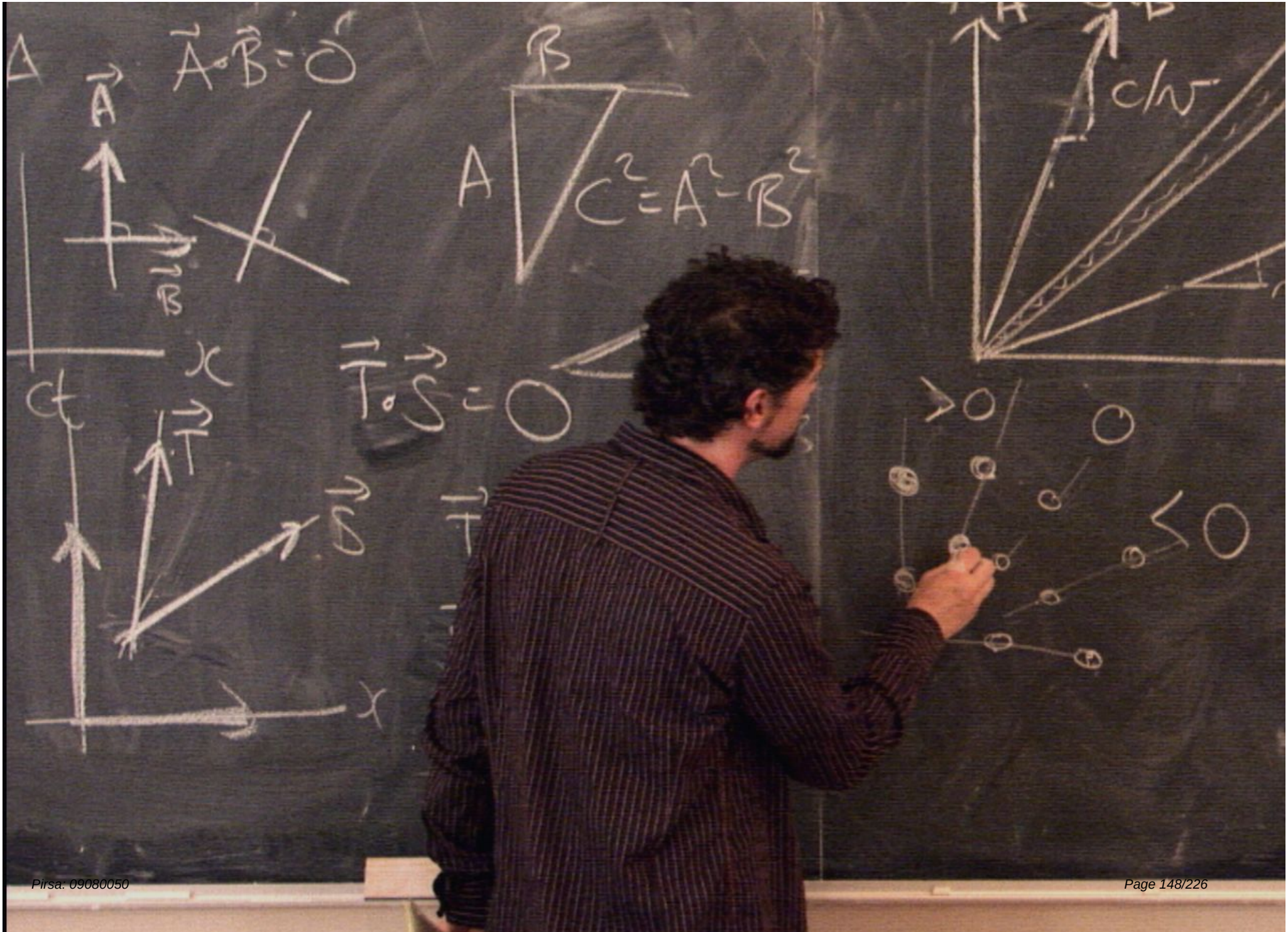

A
$\vec{A}$
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{B}$
x
B
A
$C^2 = A^2 - B^2$
C
$\vec{T}$
$\vec{T}$
O

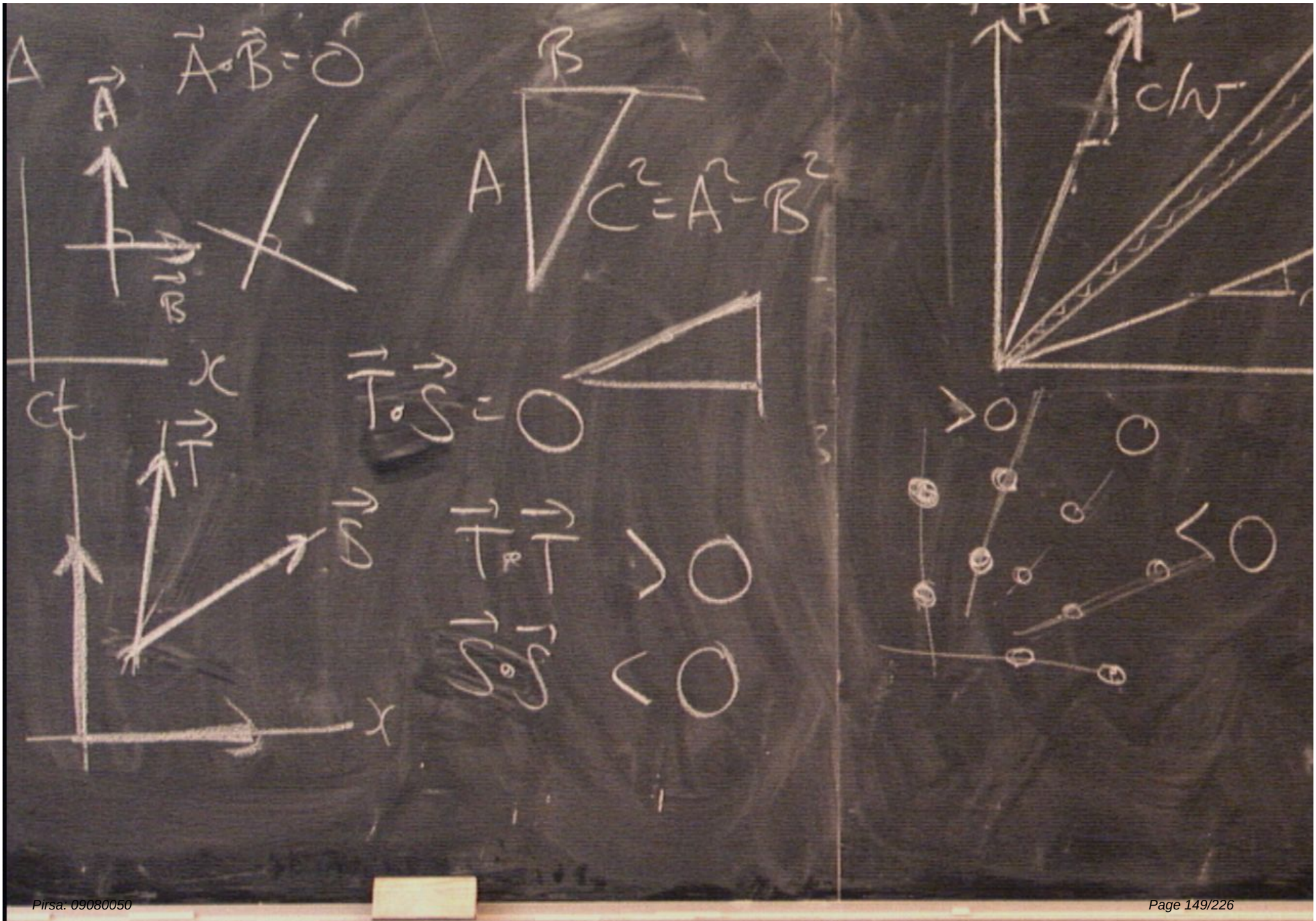

A
$\vec{A}$
$\vec{A}+\vec{B}=\vec{0}$
y
$\vec{B}$
x
t
$\vec{T}$
B
A
$C^2=A^2+B^2$
$\vec{T}_0$
$\vec{T}>0$
$\vec{T}<0$
C


A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
B
A
$C^2 = A^2 - B^2$
C
$\vec{S} = 0$
$\vec{T} \cdot \vec{T} > 0$
$\vec{S} \cdot \vec{S} < 0$


A
$\vec{A} \cdot \vec{B} = 0$
B
$C^2 = A^2 + B^2$
$\vec{T}_R \vec{T} > 0$
< 0

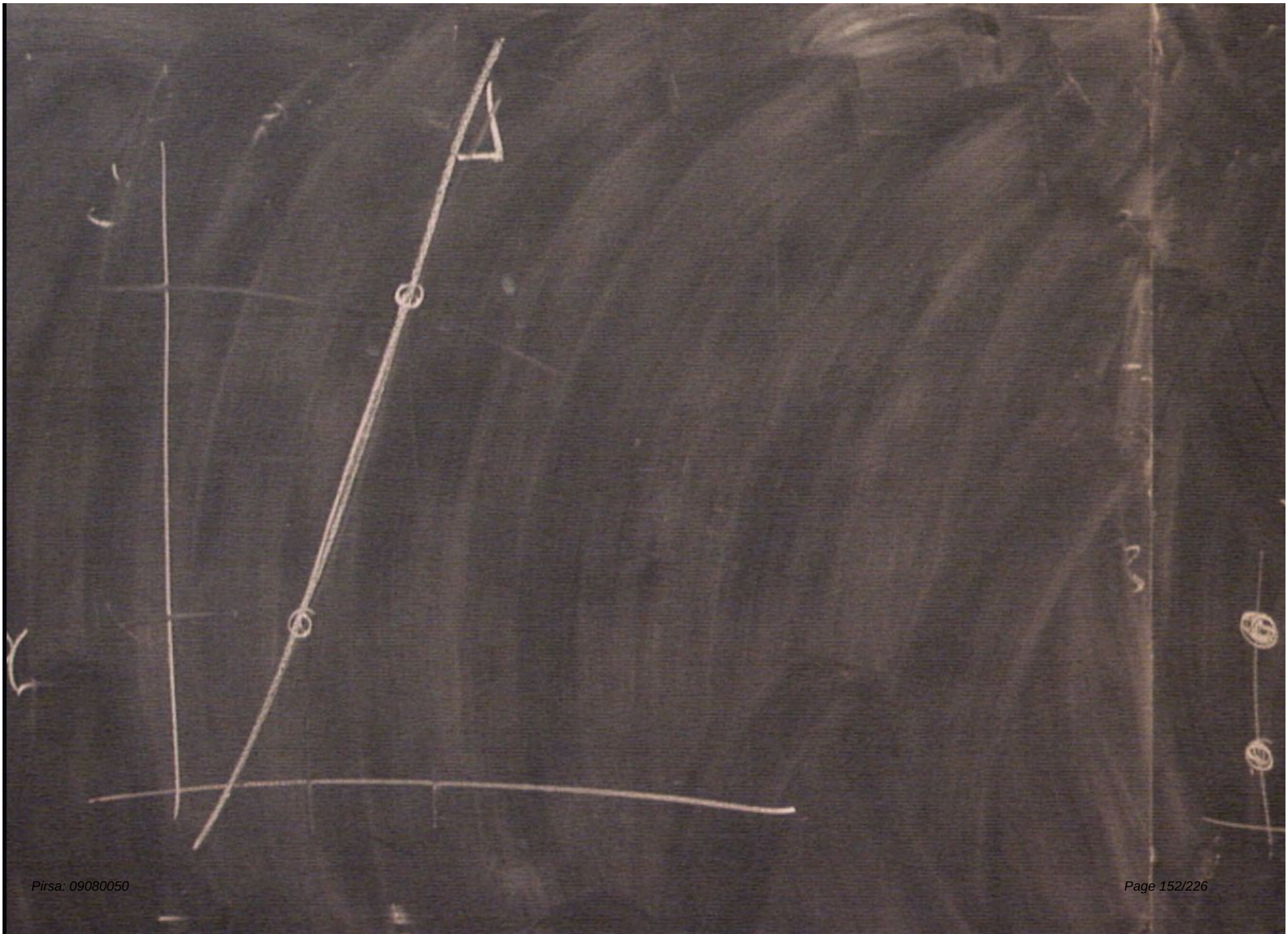

A
$\vec{A} \cdot \vec{B} = 0$
y
$\vec{A}$
$\vec{B}$
x
B
A
$C^2 = A^2 - B^2$
$\vec{T} \cdot \vec{S}$
$\vec{T}$
> 0
< 0

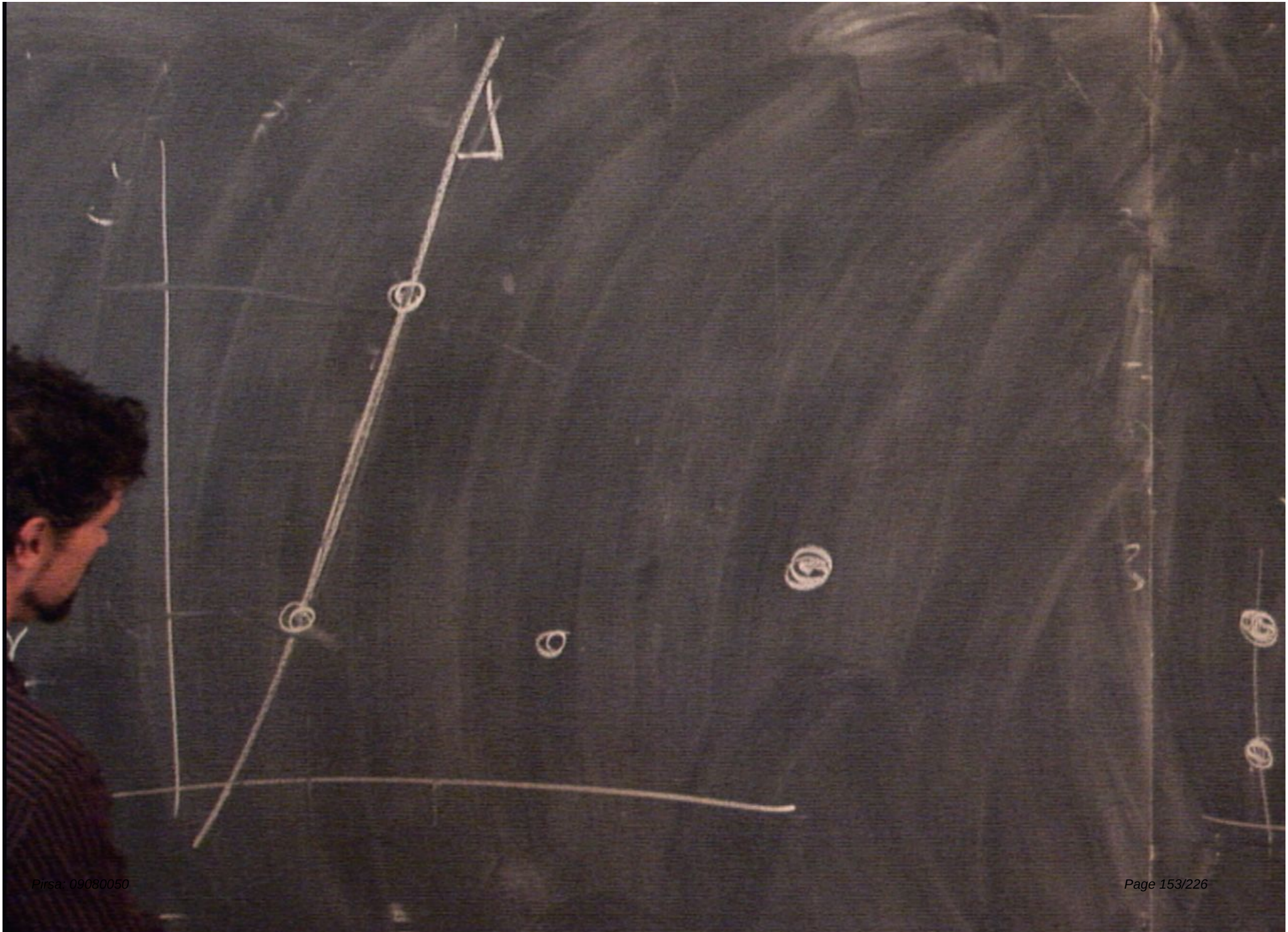

A
$\vec{A} \cdot \vec{B} = 0$
$\vec{A}$
$\vec{B}$
B
A
$C^2 = A^2 + B^2$
C/N
x
$\vec{T} \cdot \vec{S} = 0$
t
$\vec{T}$
$\vec{S}$
$\vec{T}$
x
>0
0
<0

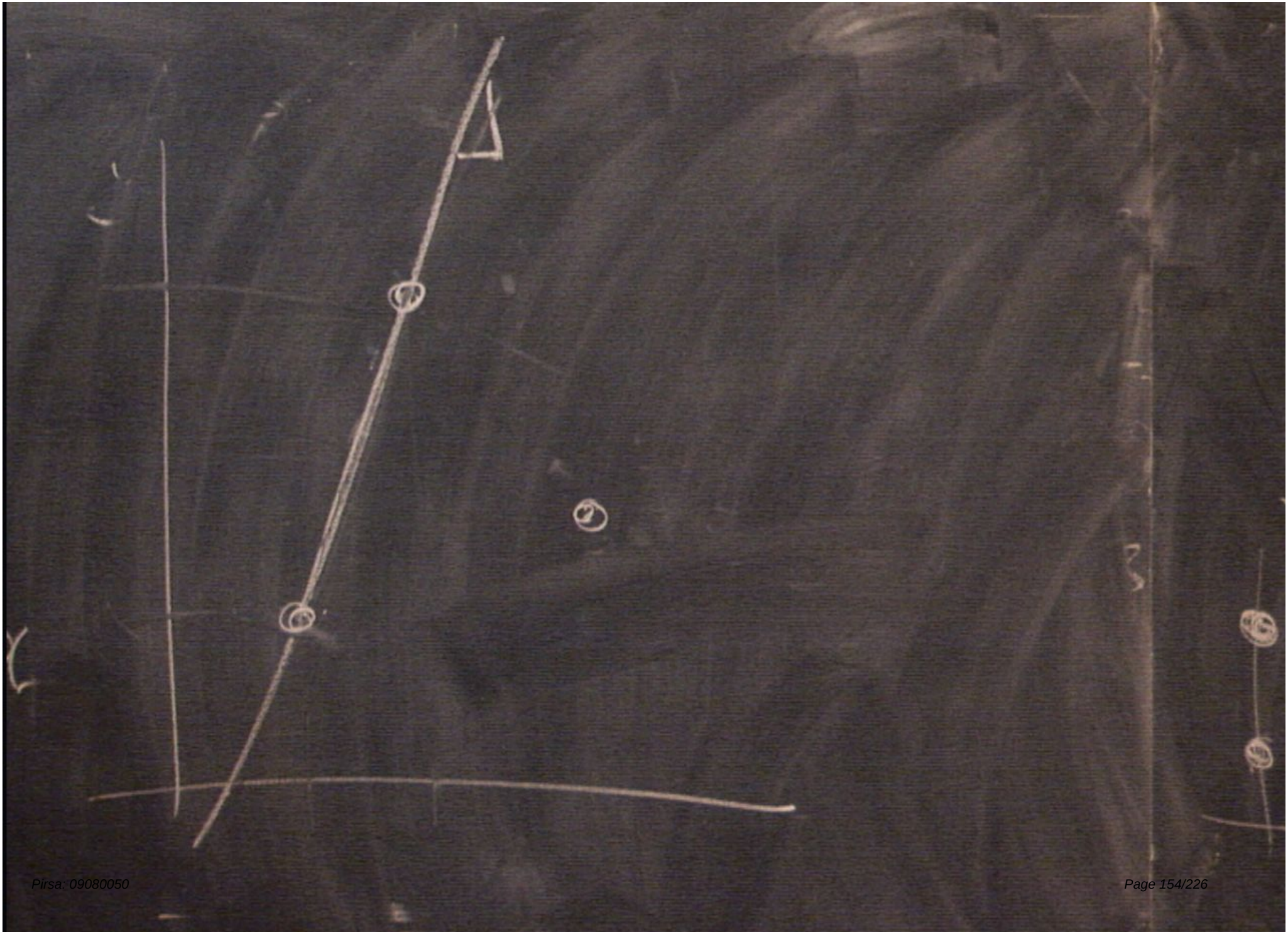

A
$\vec{A} \cdot \vec{B} = 0$
$\vec{A}$
$\vec{B}$
B
A
$C^2 = A^2 + B^2$
C/N
$\vec{T} \cdot \vec{S} = 0$
$\vec{T}$
$\vec{S}$
$\vec{T}_R \cdot \vec{T} > 0$
$\vec{S} \cdot \vec{S} < 0$
> 0
0
< 0

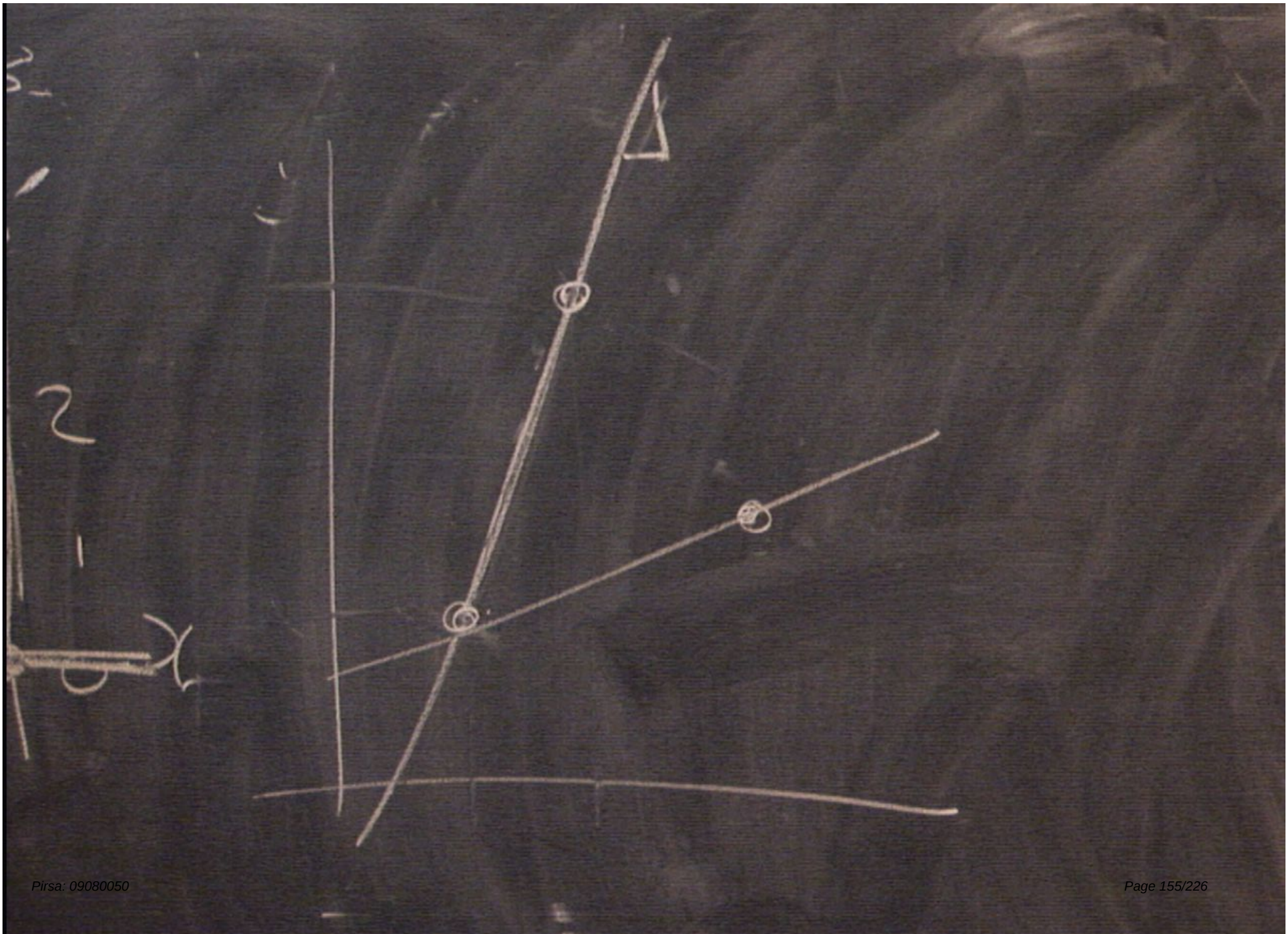


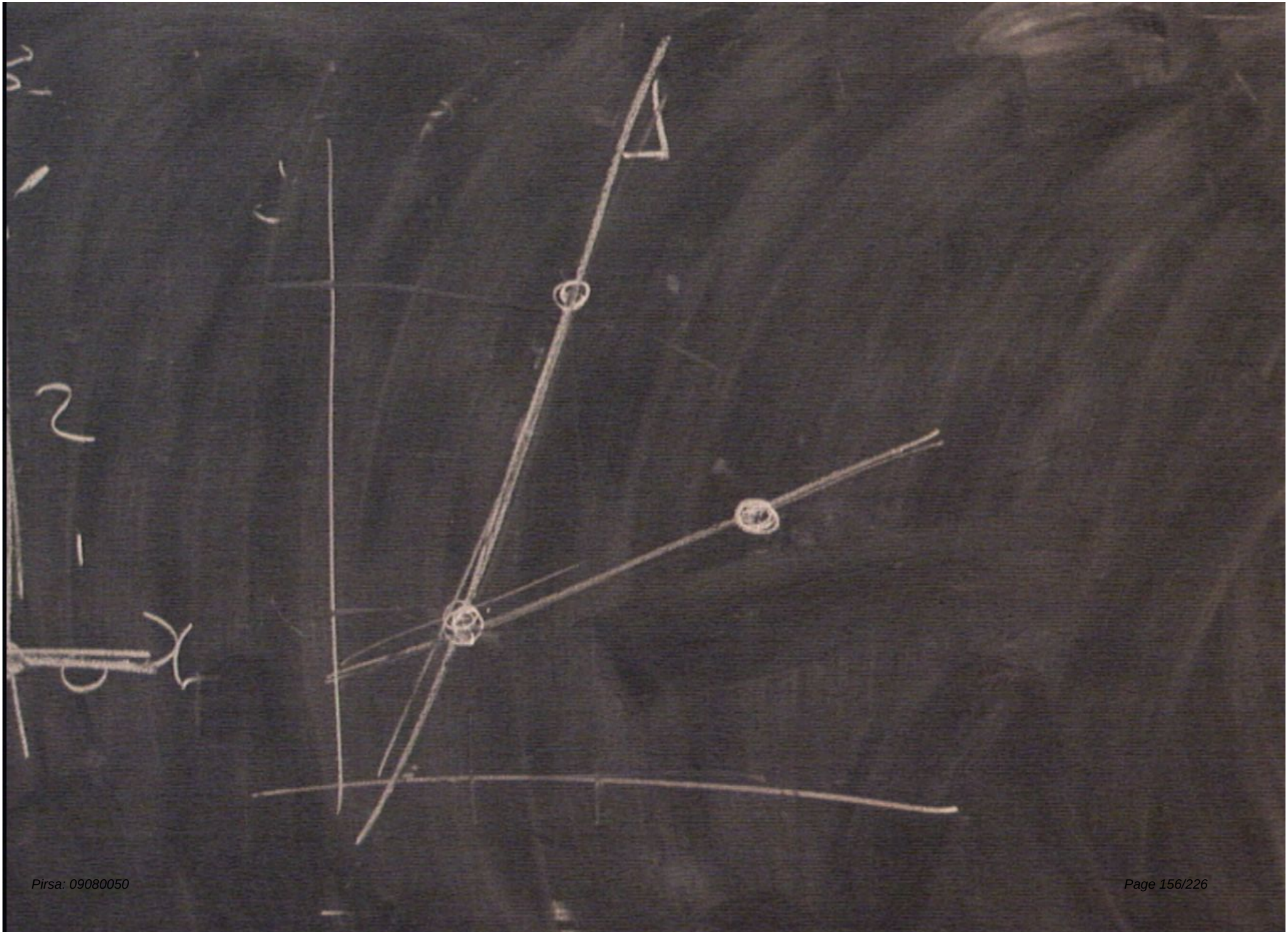


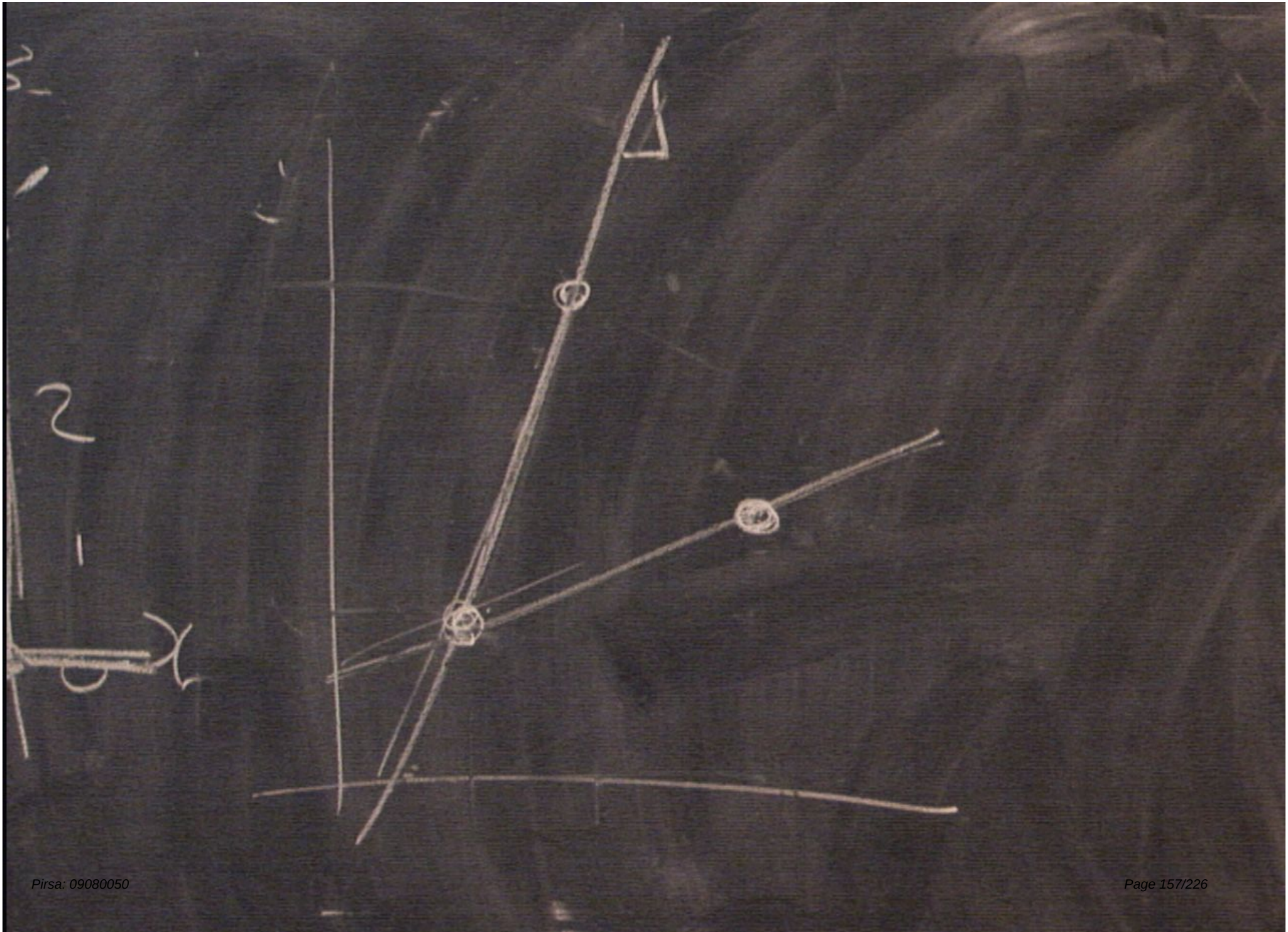


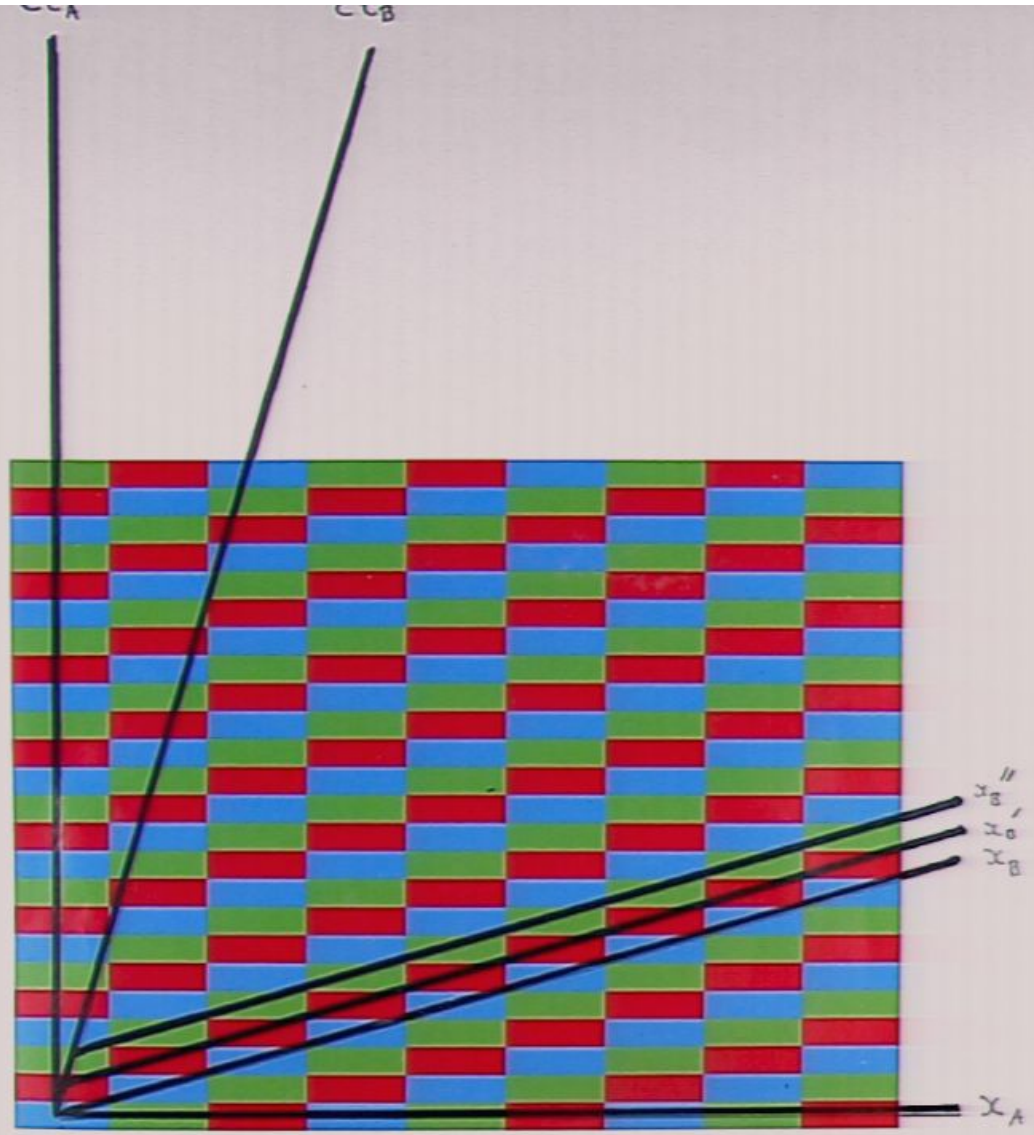


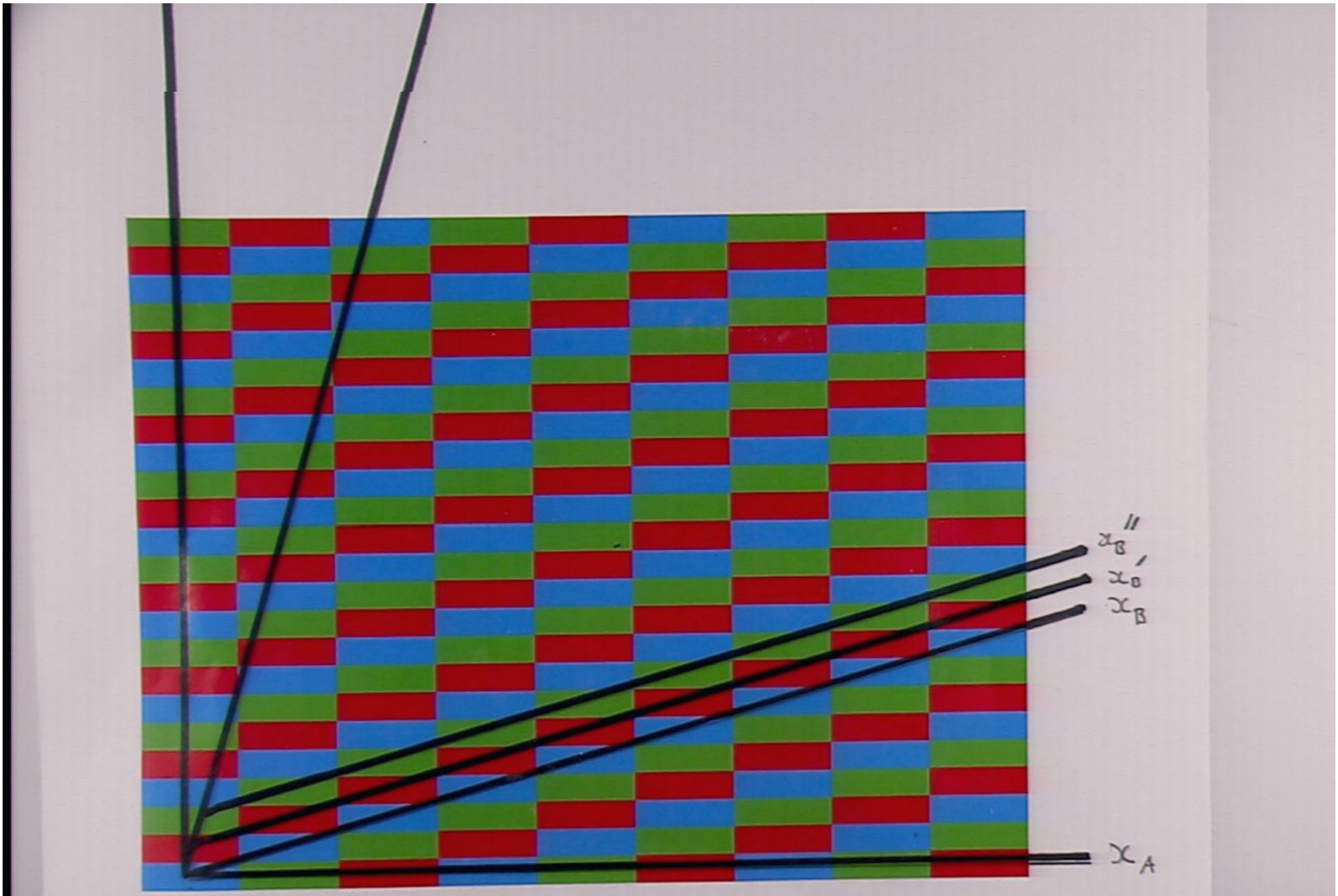


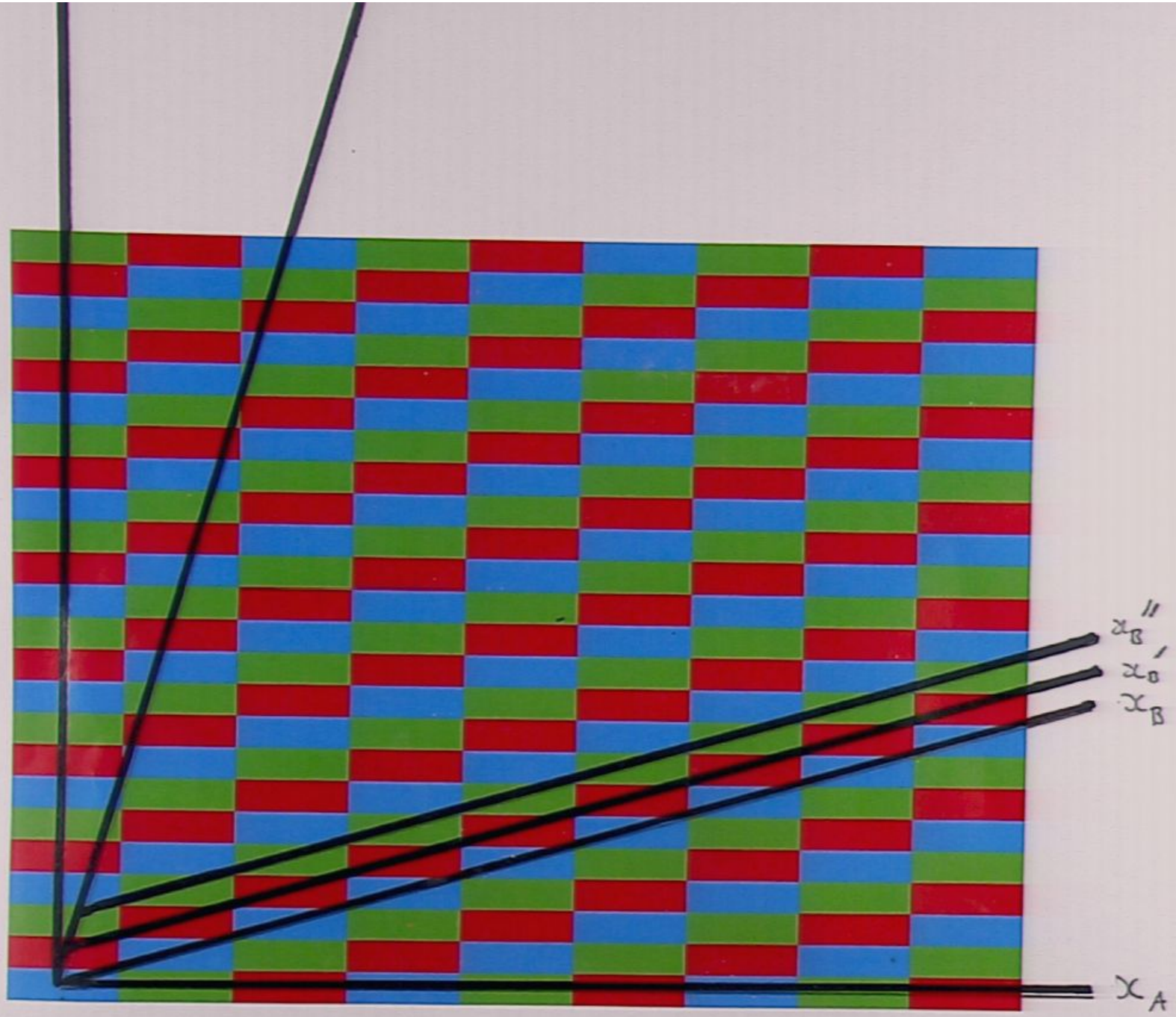


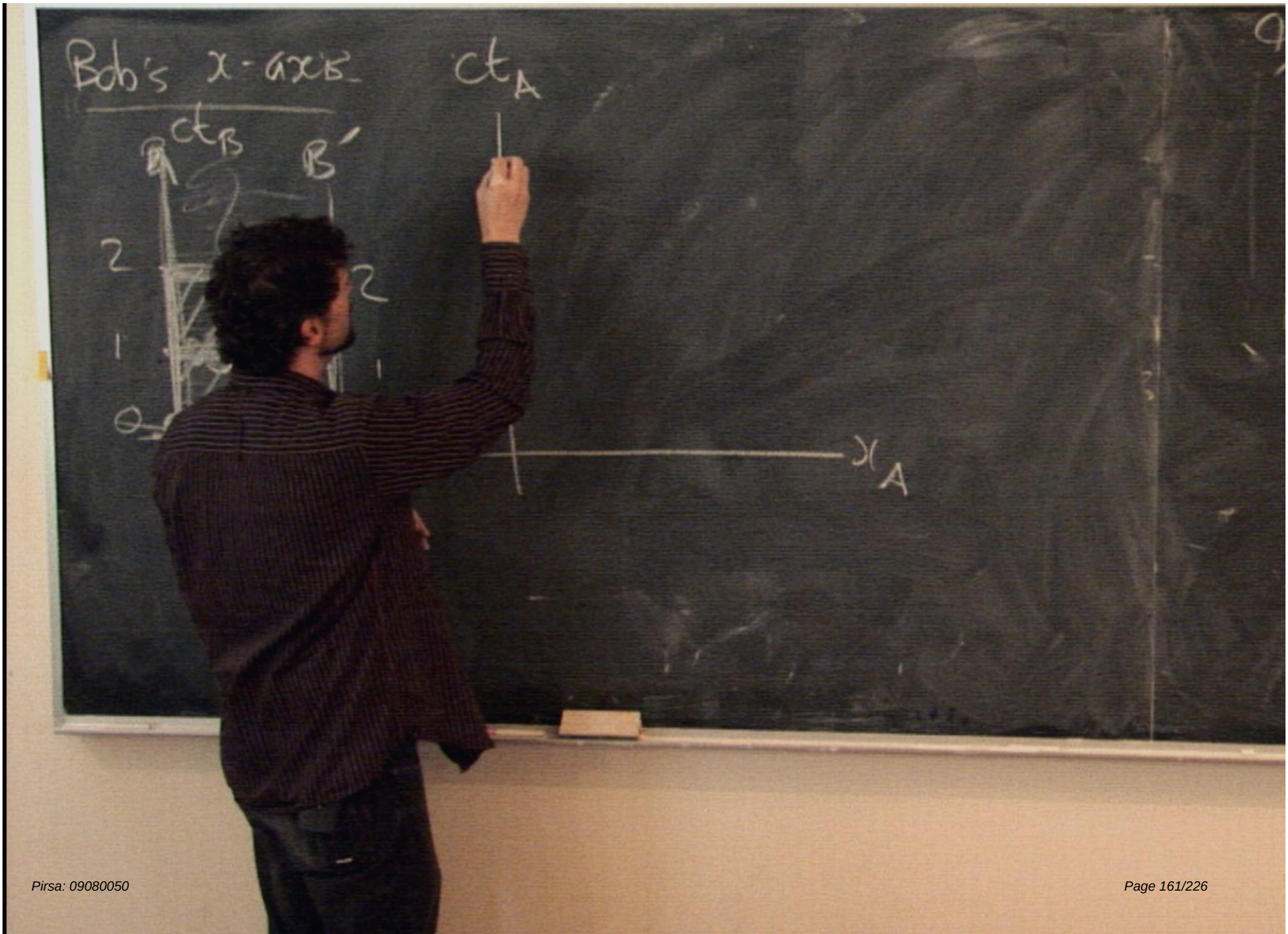


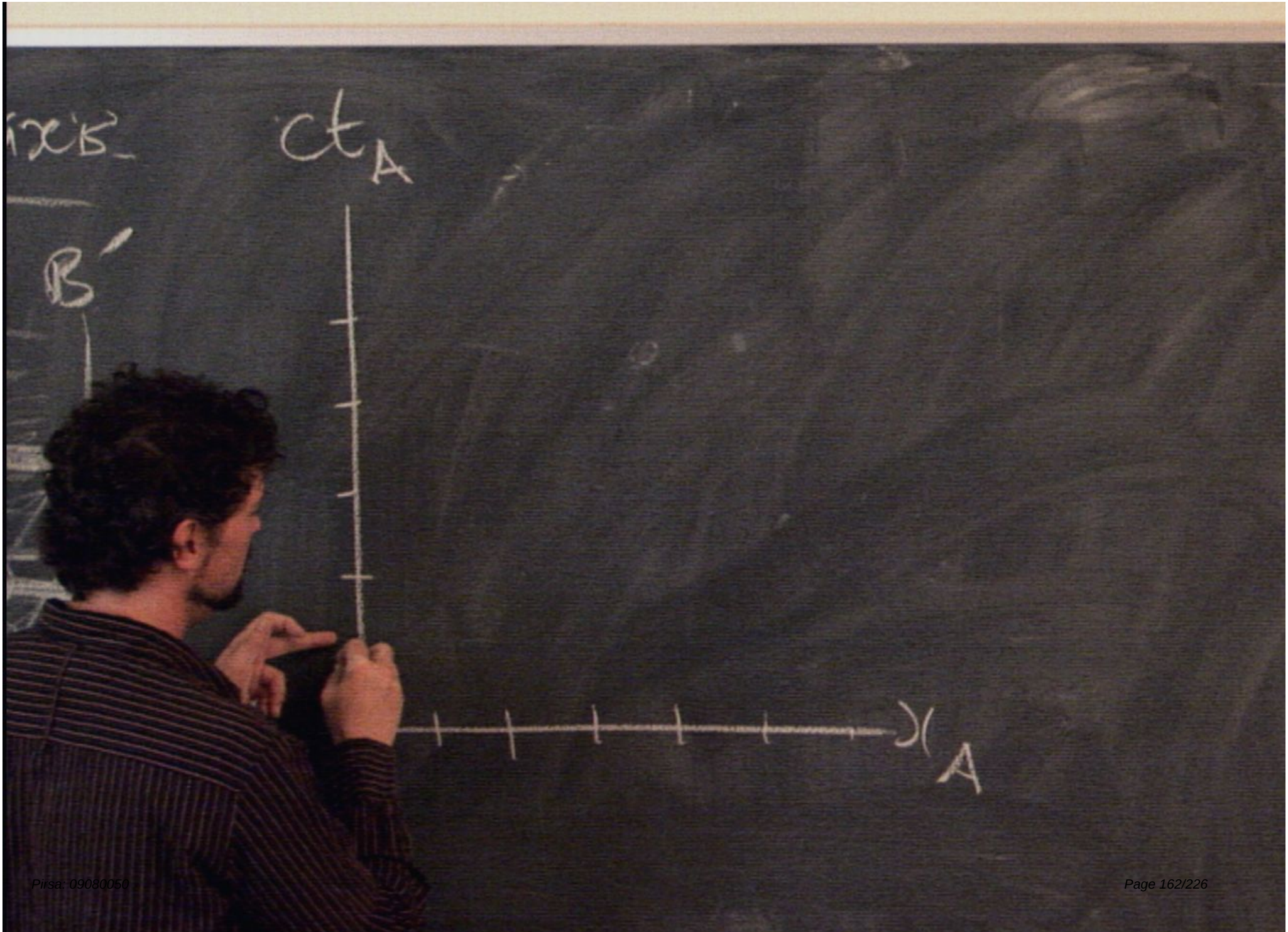



μ_A
μ_B
x_B''
x_B'
x_B
x_A


x_B''
x_B'
x_B
x_A


x_B''
x_B'
x_B
x_A

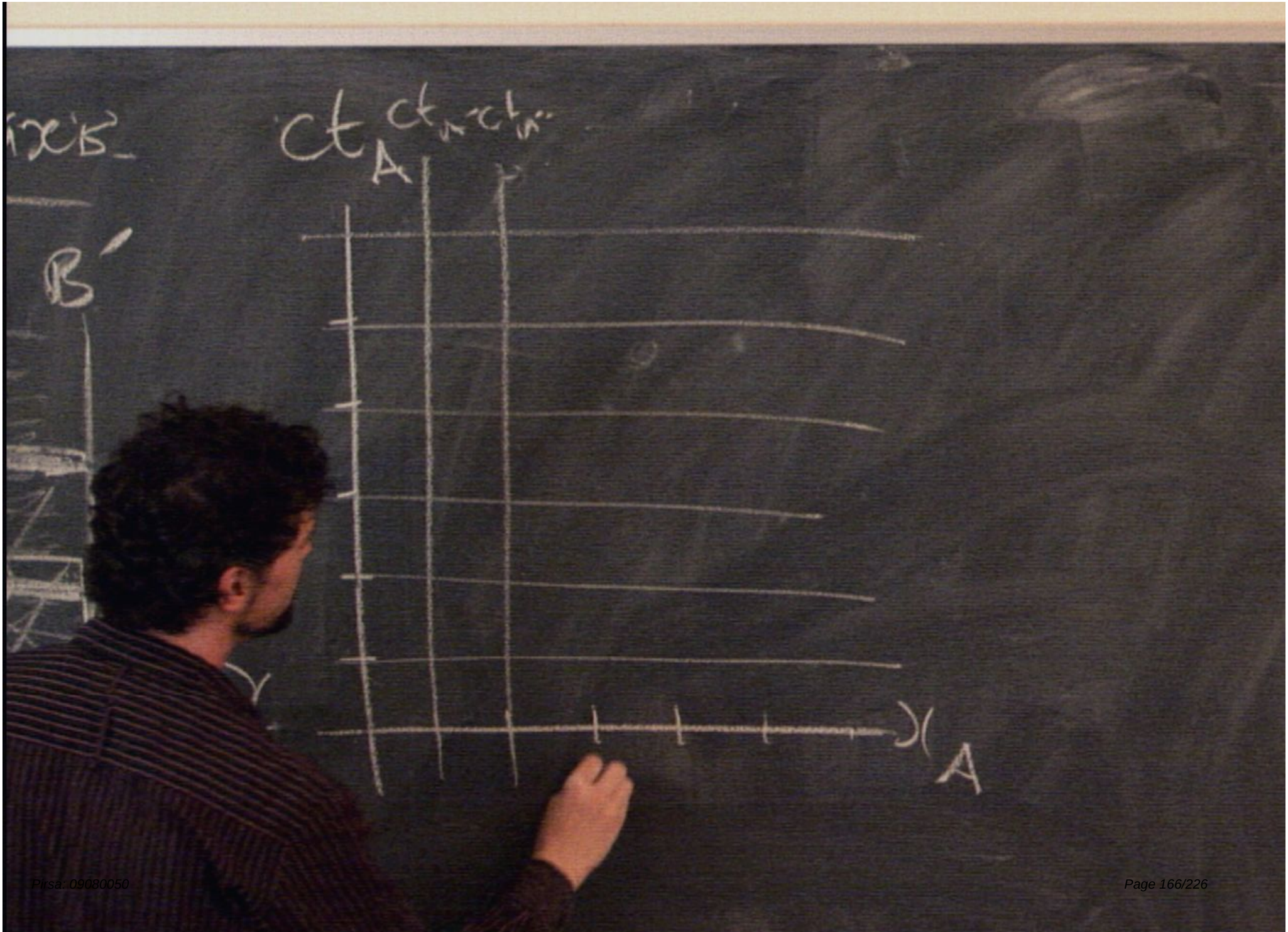

Bob's x - axis
ct_B
B
B'
2
1
2
1
ct_A
x_A

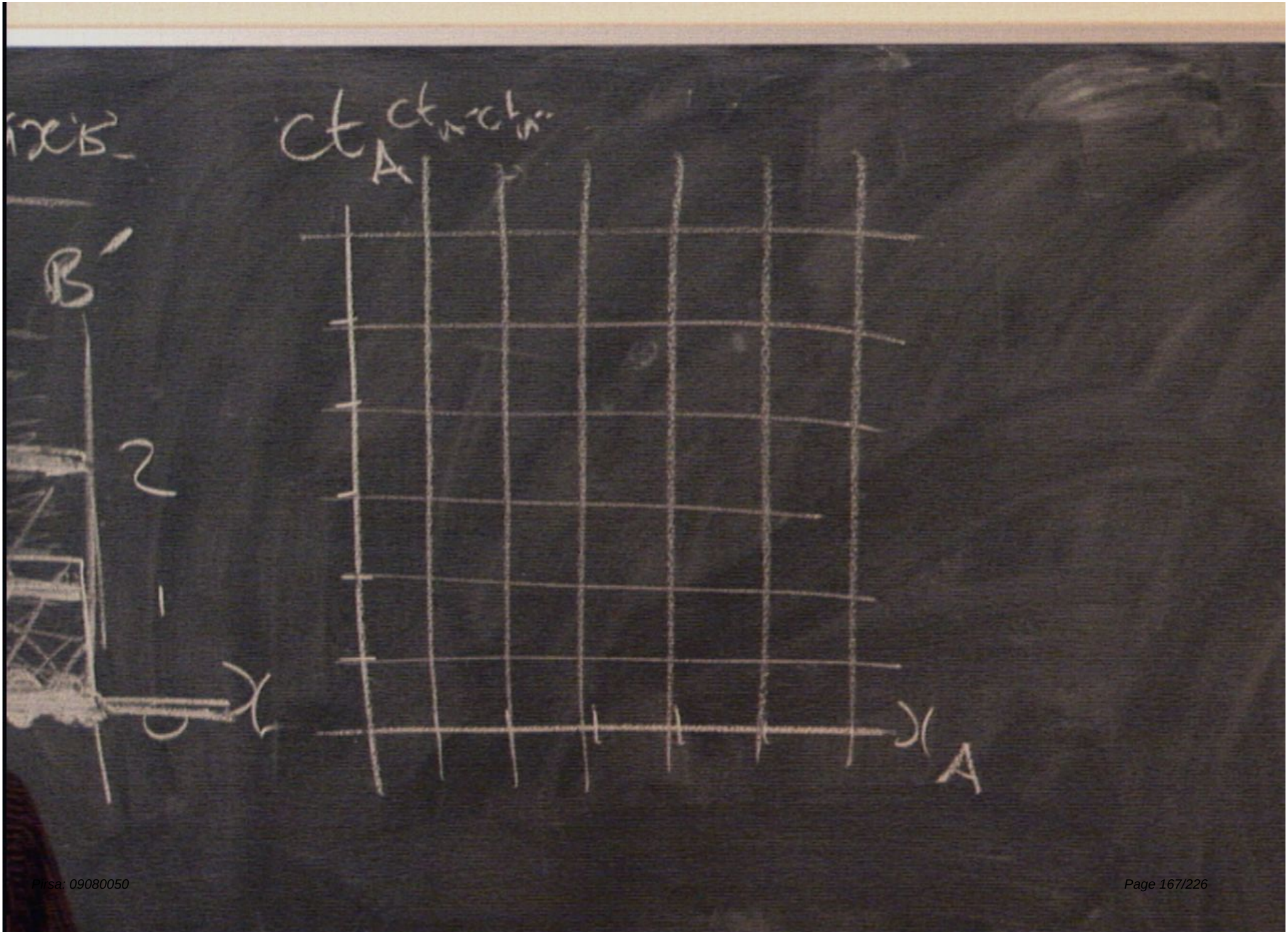

ct_A
B'
x_A

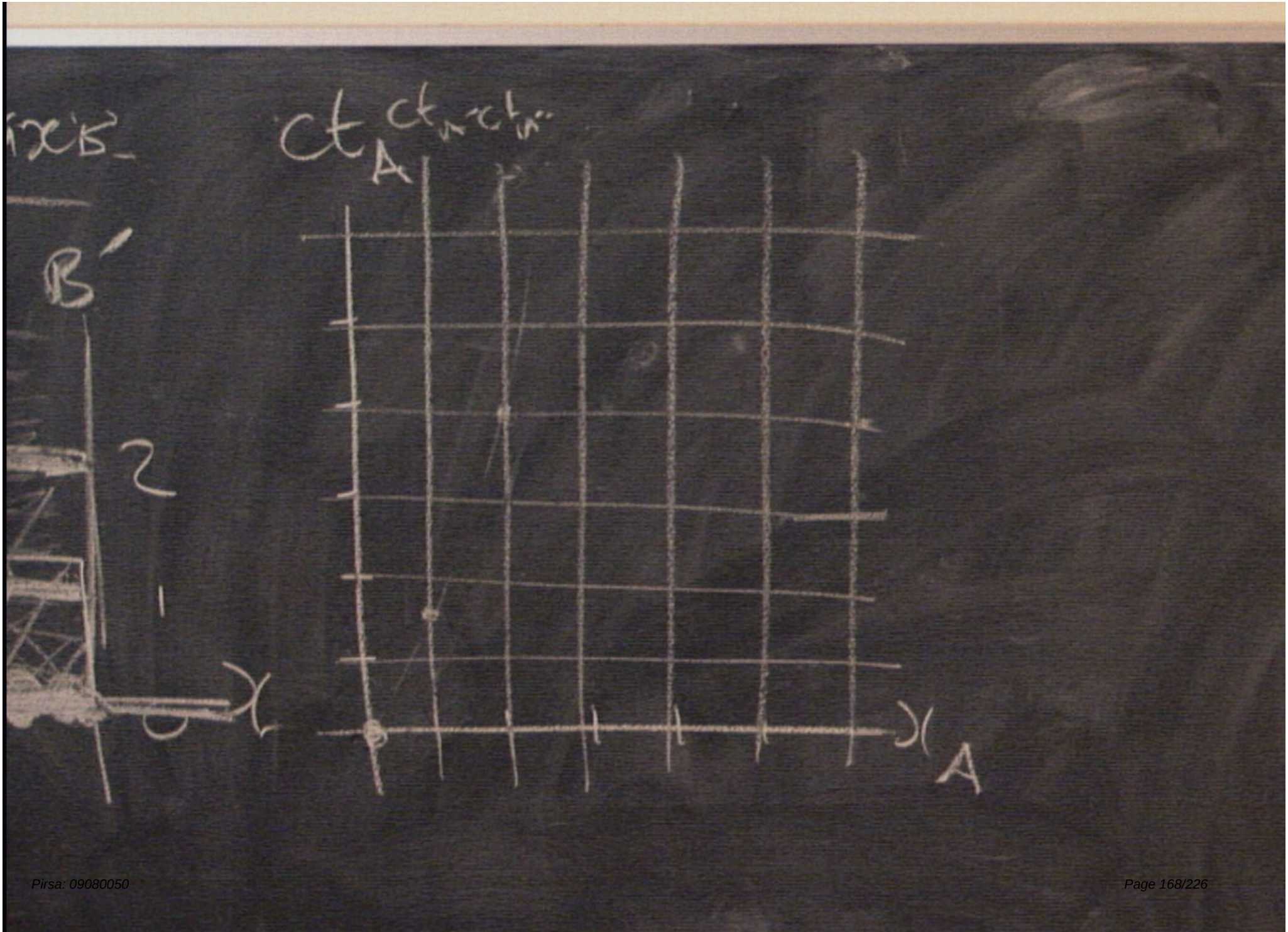

ct A
B'
x A

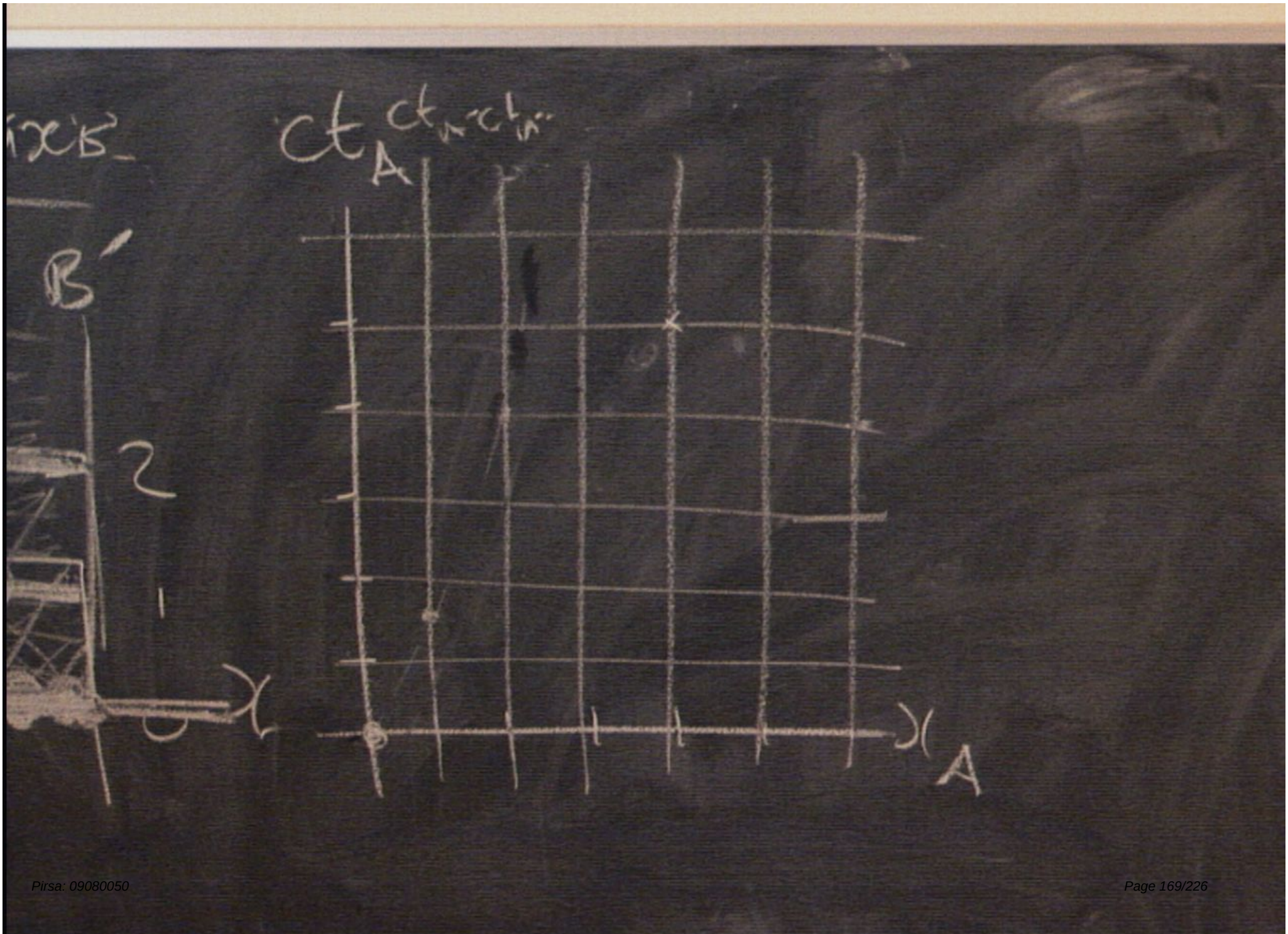

ct_A
B'
x_A


ct
ct'
A
B'
x
x'
A


B'
A
A

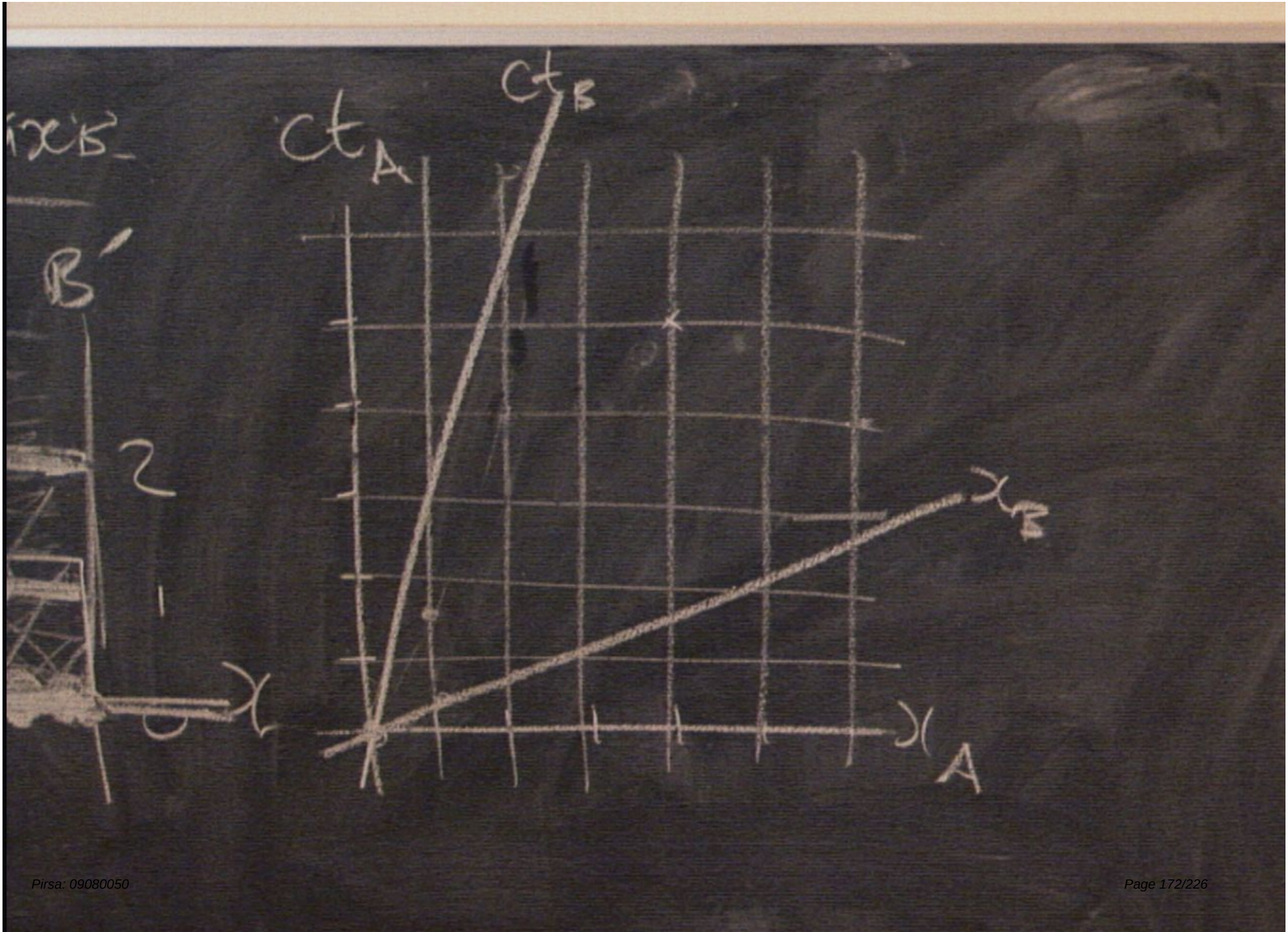

ct
A
B'
2
1
O
A


ct
B'
2
1
x
x
A

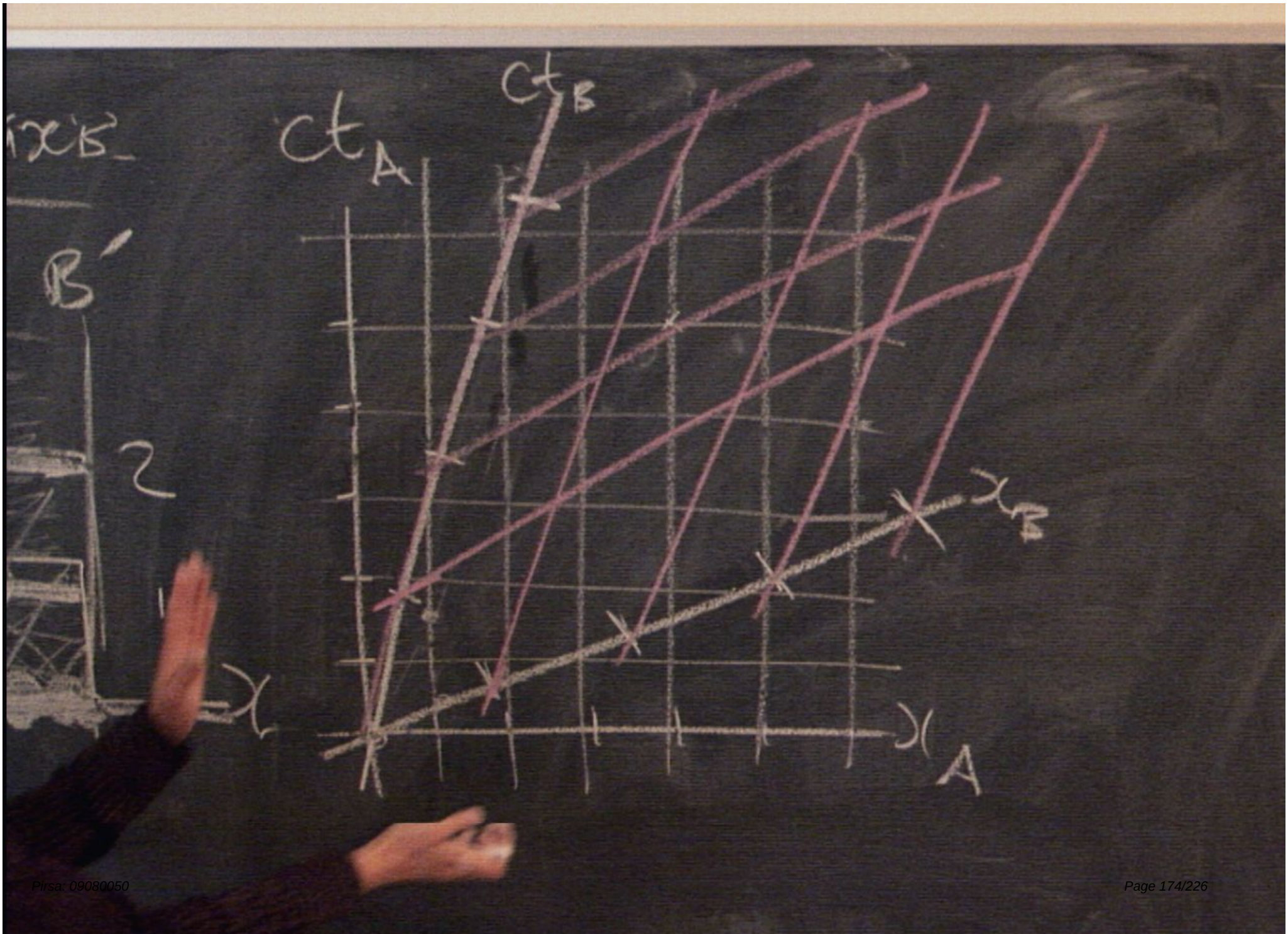

B'
2
1
A

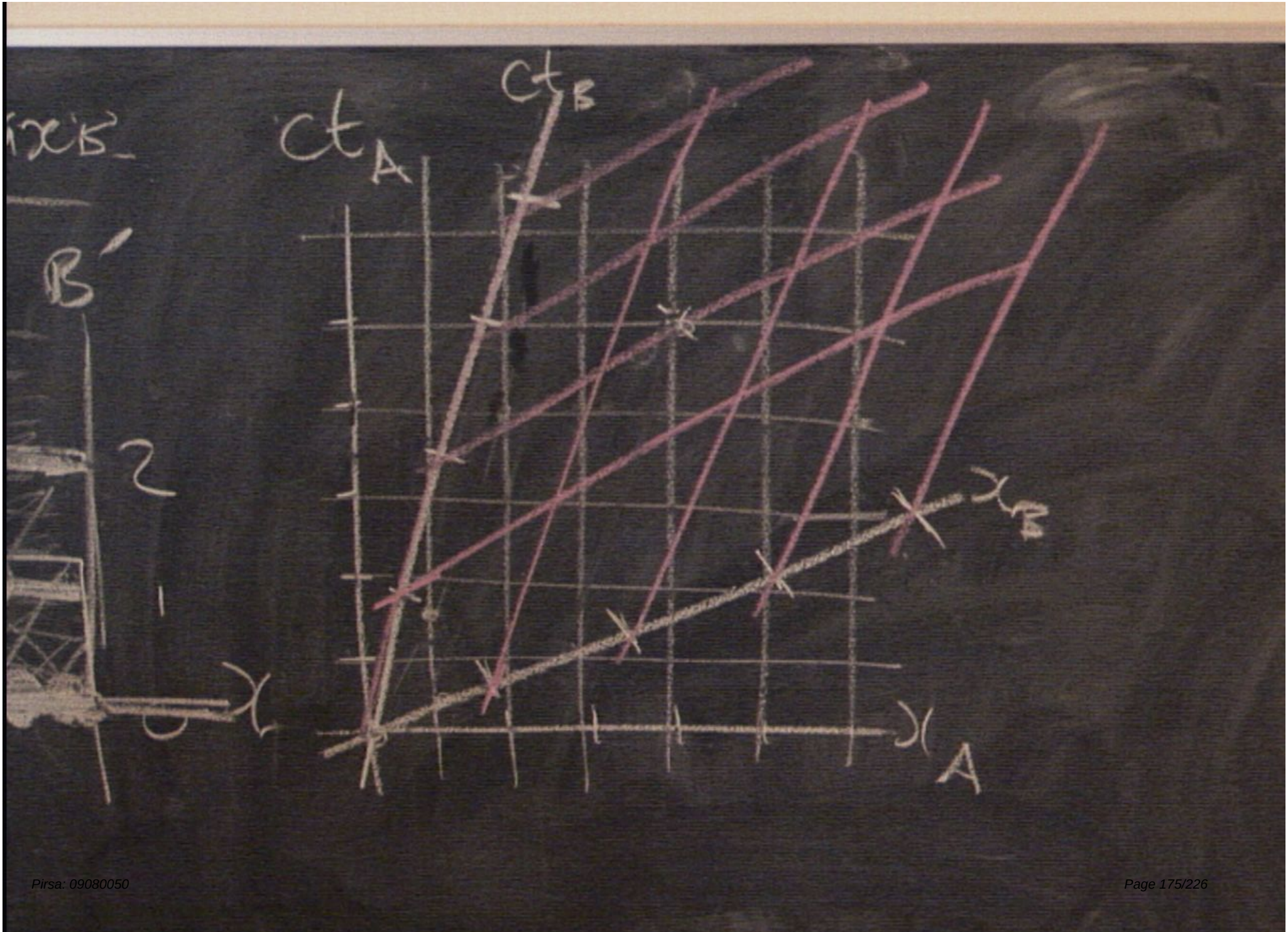

ct_B
ct_A
B'
2
1
x'
x
A

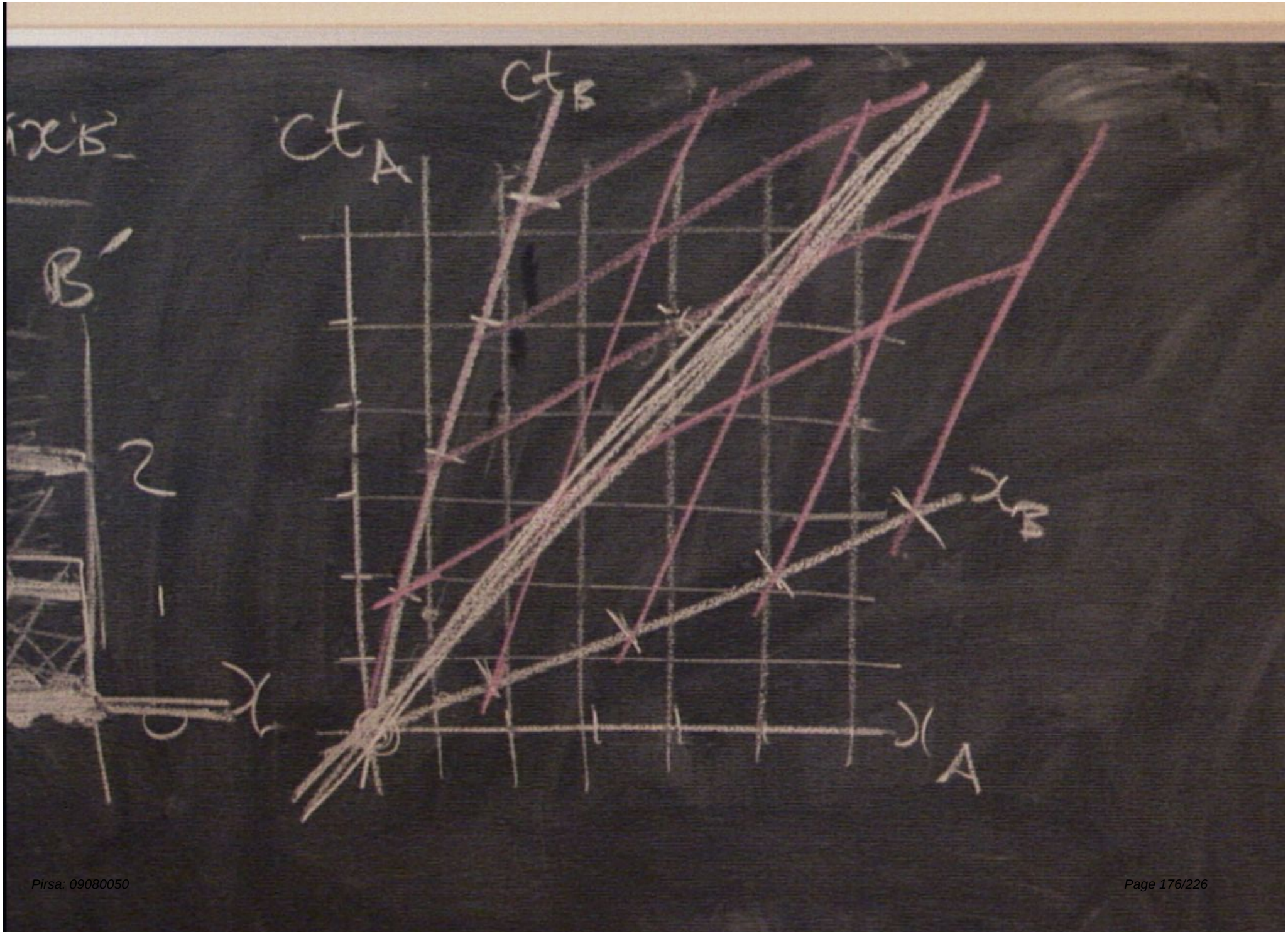

ct_B
ct_A
B'
2
1
x_B
x_A

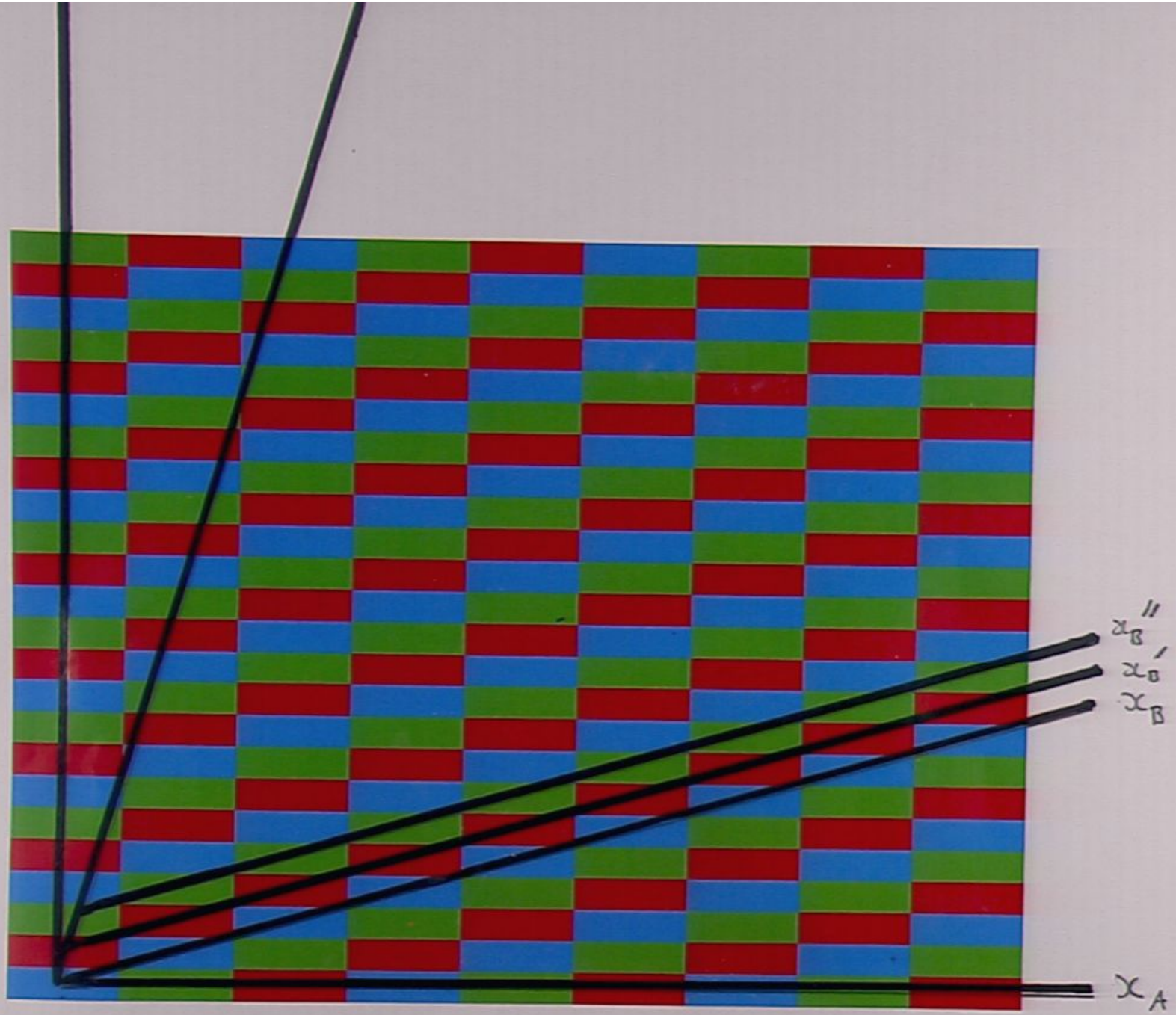

ct_B
ct_A
B'
2
x_B
x_A

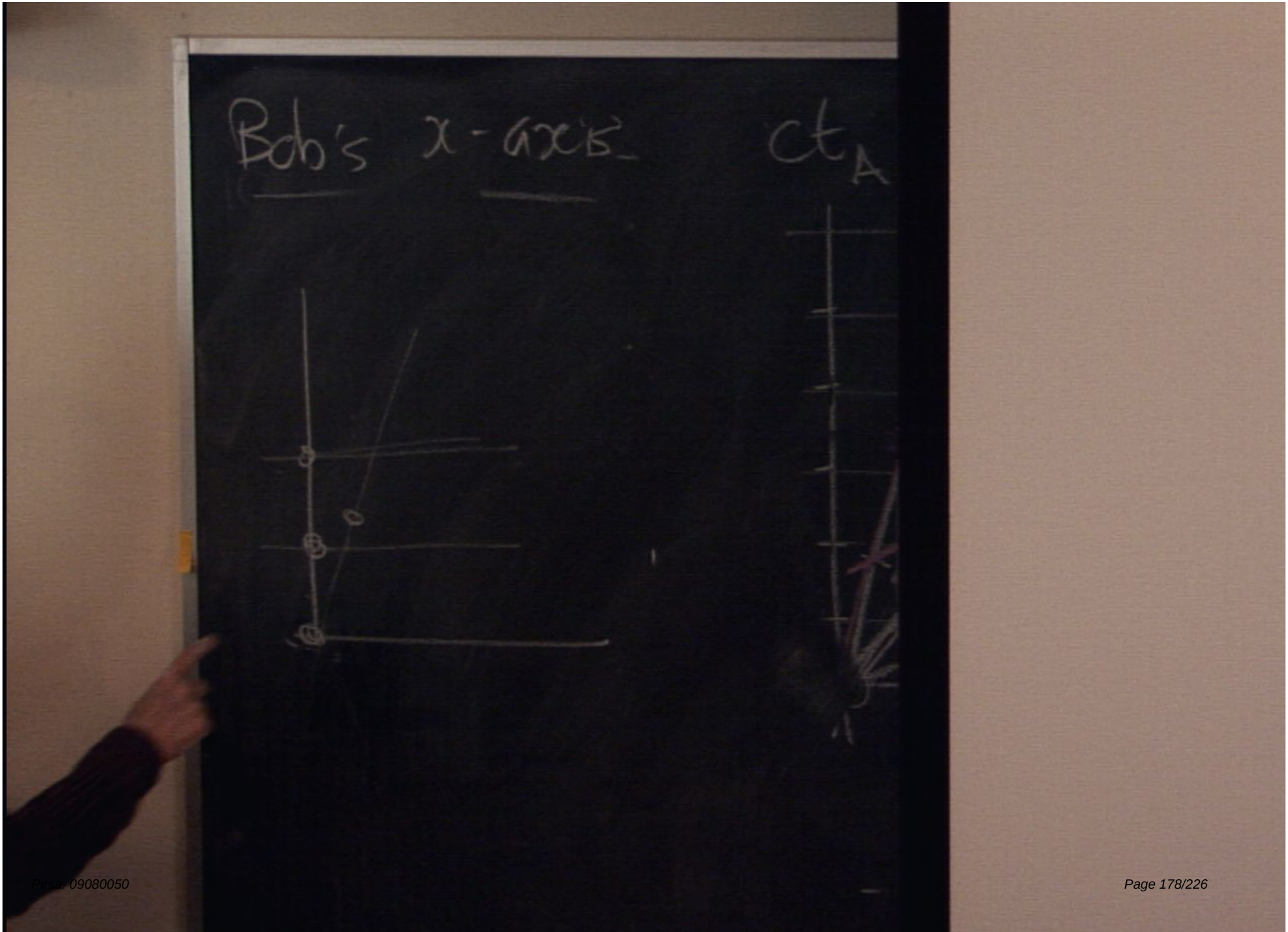

ct_B
ct_A
x'_B
B'
2
1
x_B
x_A

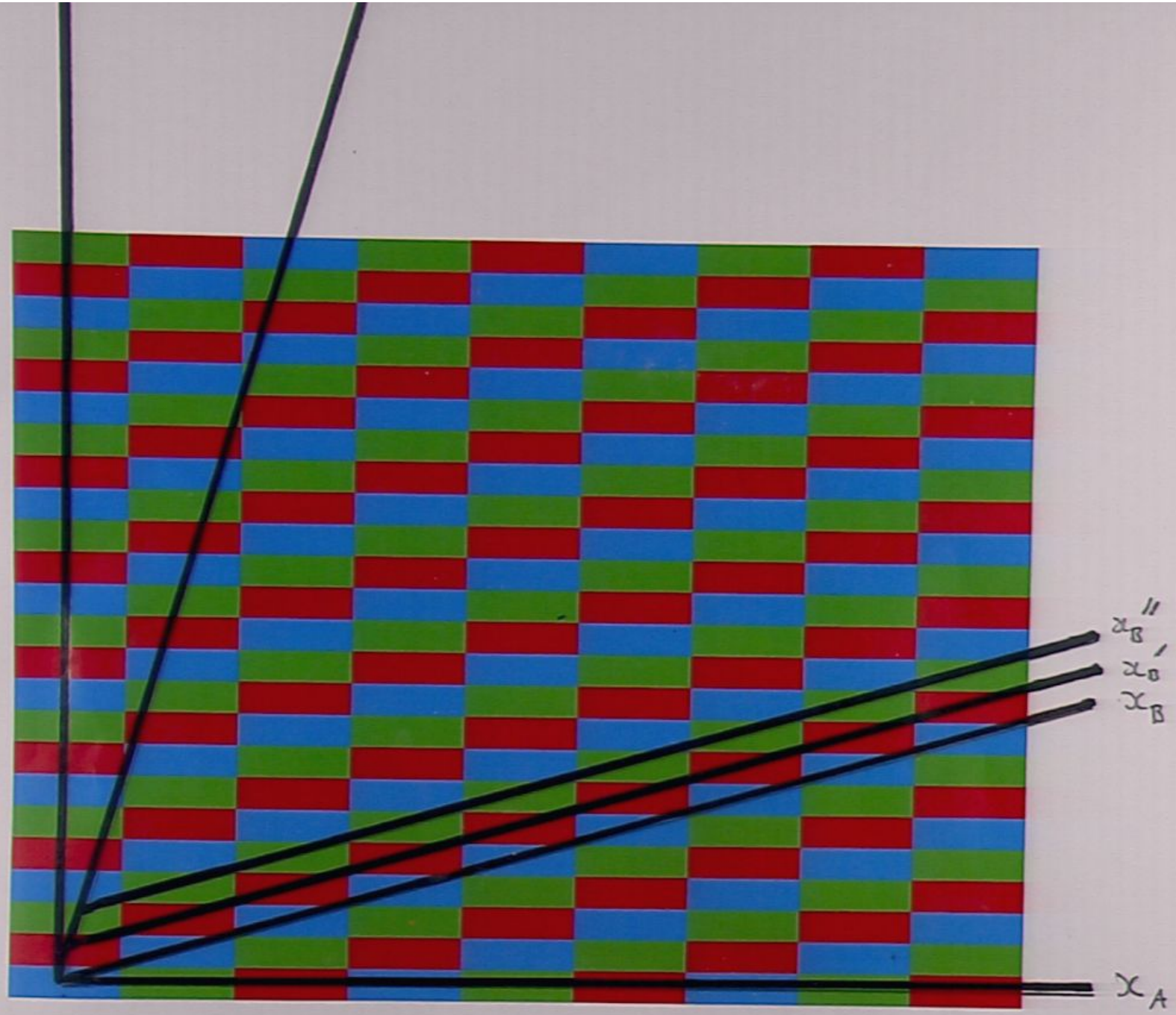

ct_B
ct_A
B'
2
x_B
x_A


ct_B
ct_A
B'
2
1
x_B
x_A


ct_B
ct_A
B'
2
1
x_B
x_A


x_B''
x_B'
x_B
x_A


Bob's x - axis
ct A

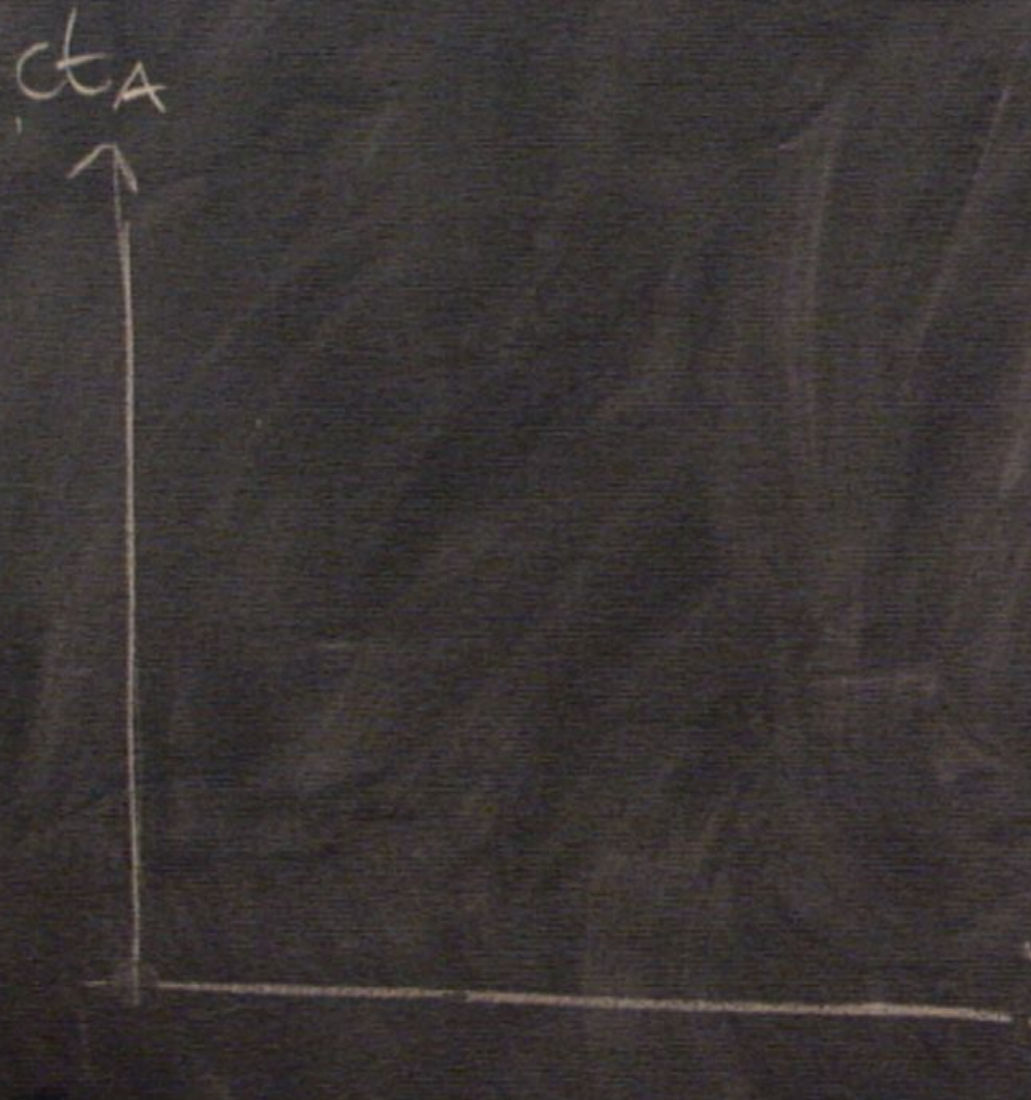

x_B''
x_B'
x_B
x_A

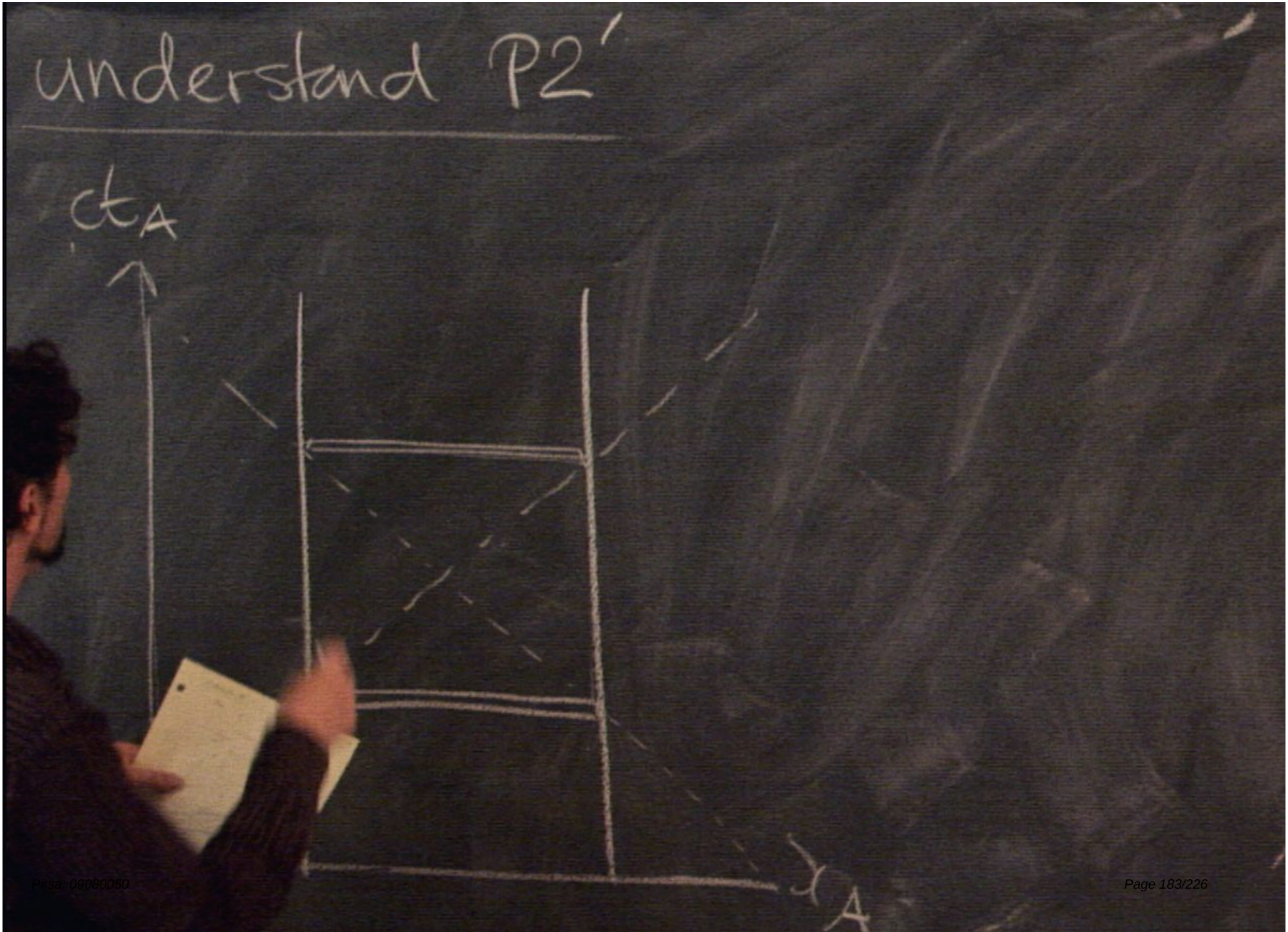
understand P2'

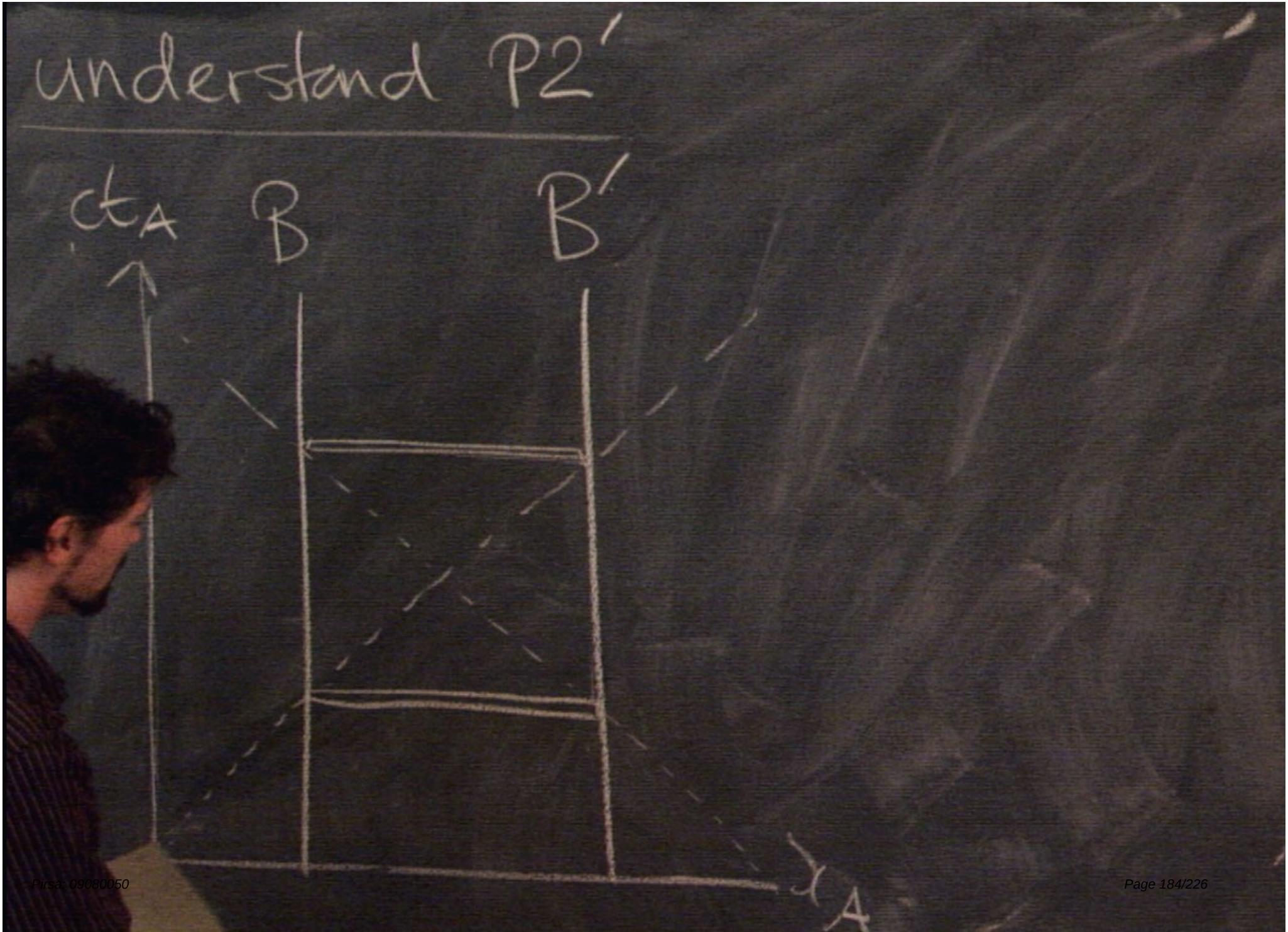
understand P2'



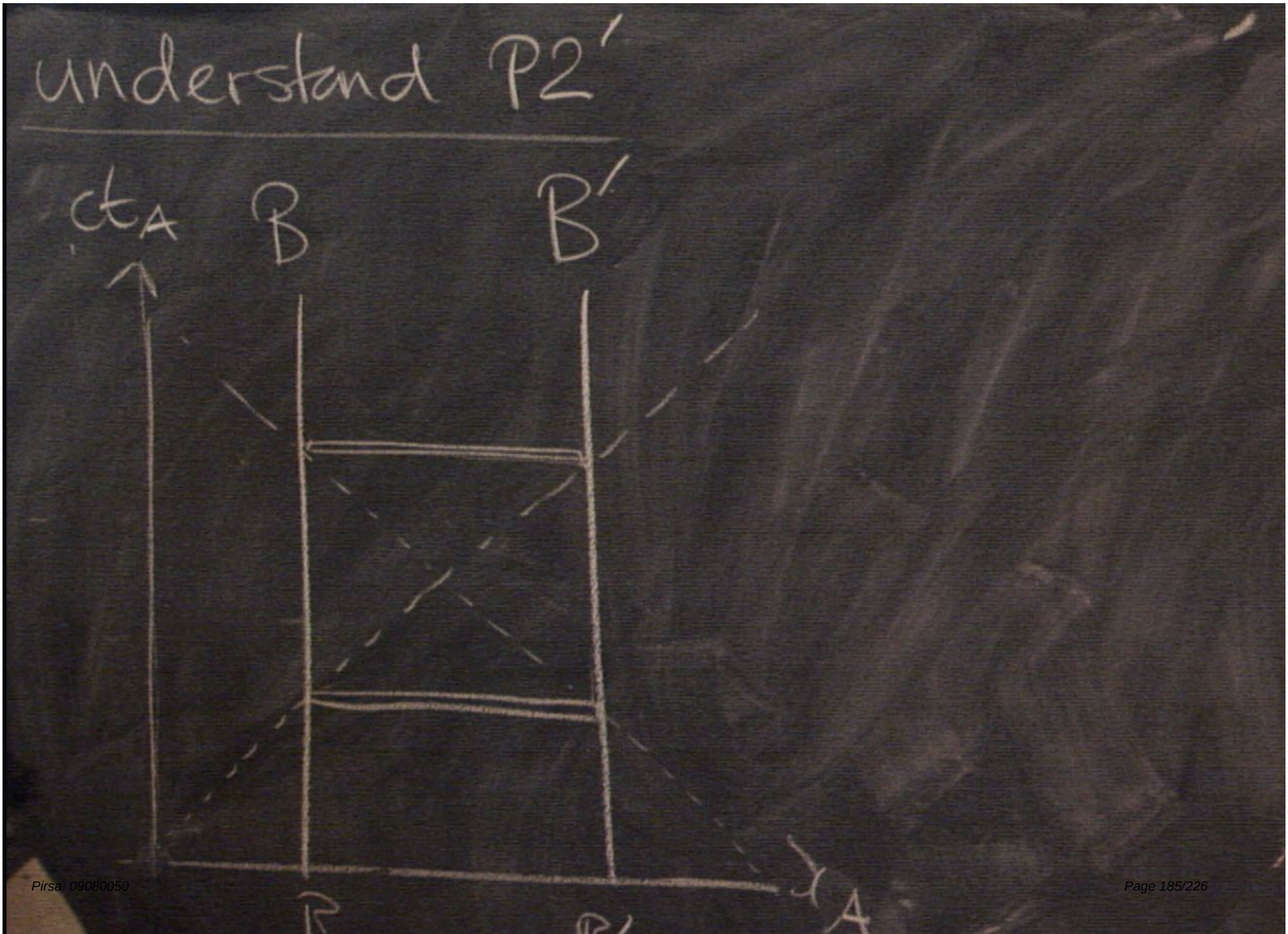
understand P2'



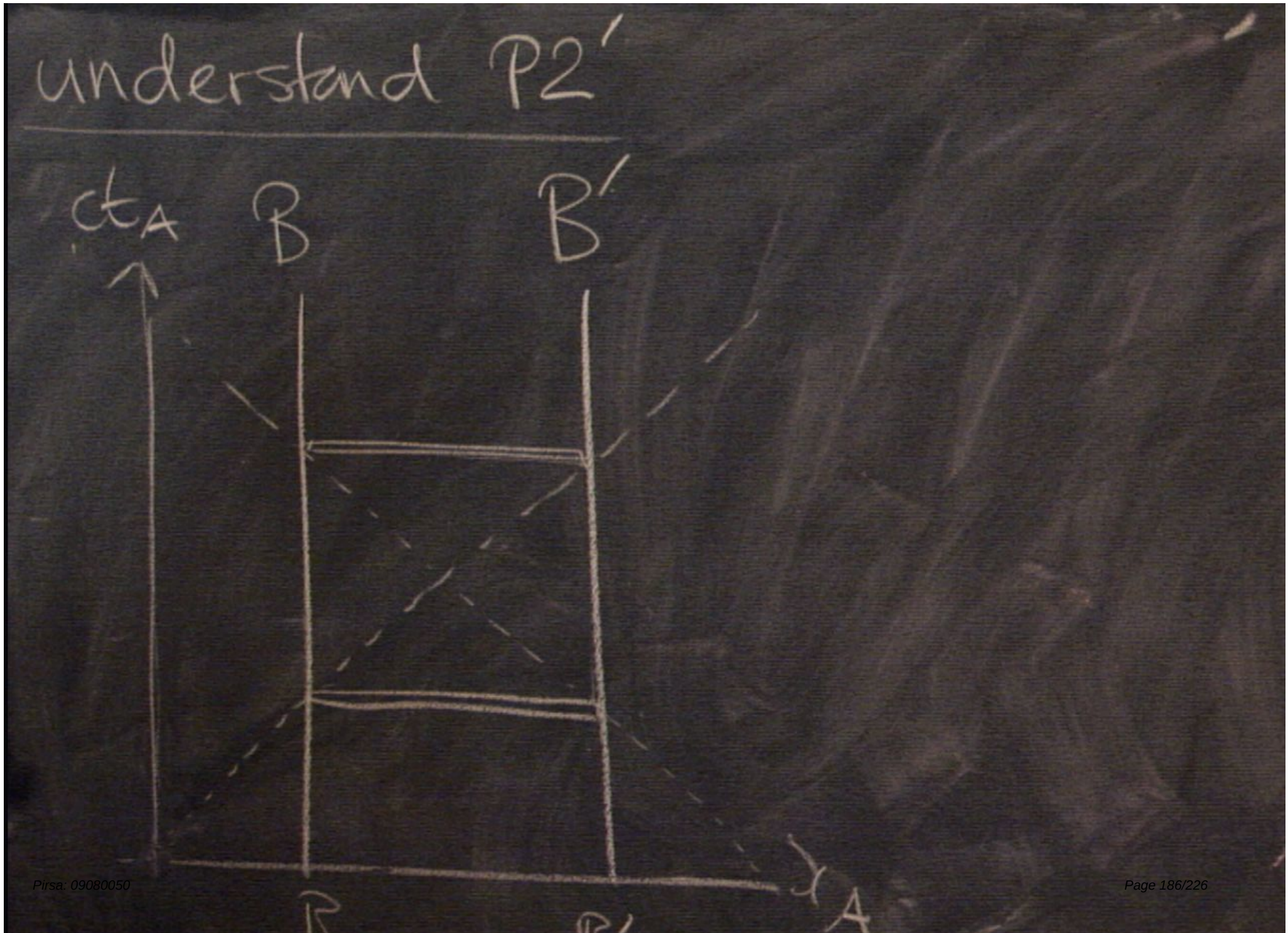

understand P2'
ct_A
x_A


understand P2'
ct_A
B
B'
A

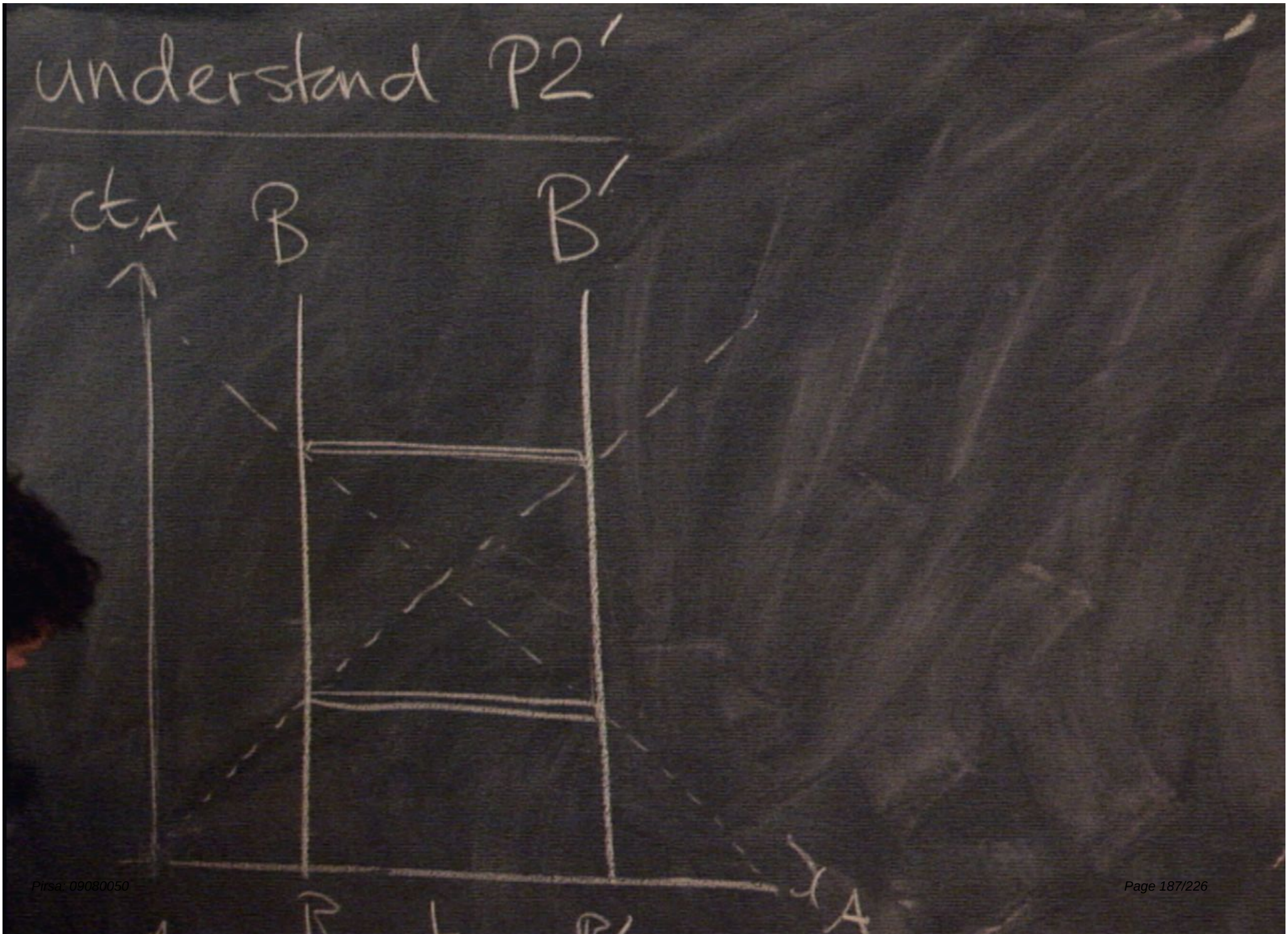
understand P2'



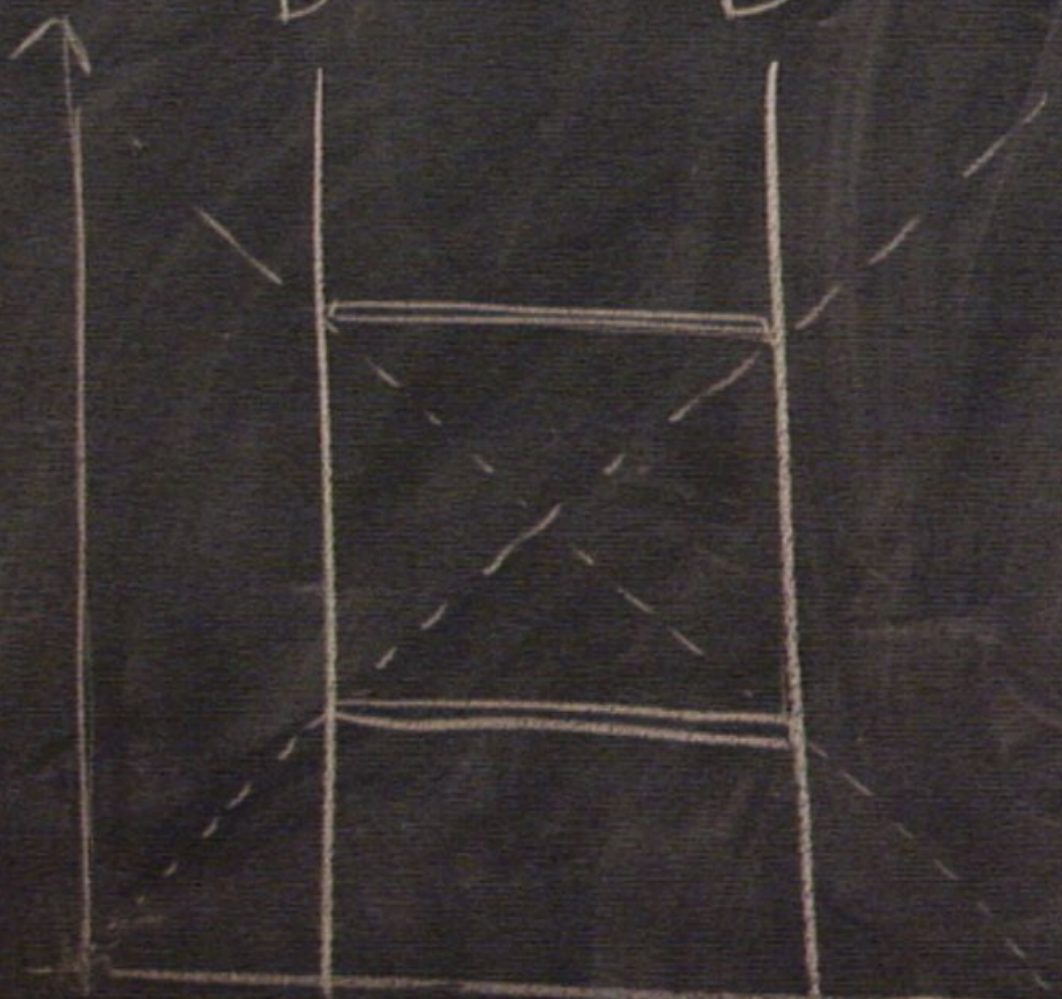
understand P2'



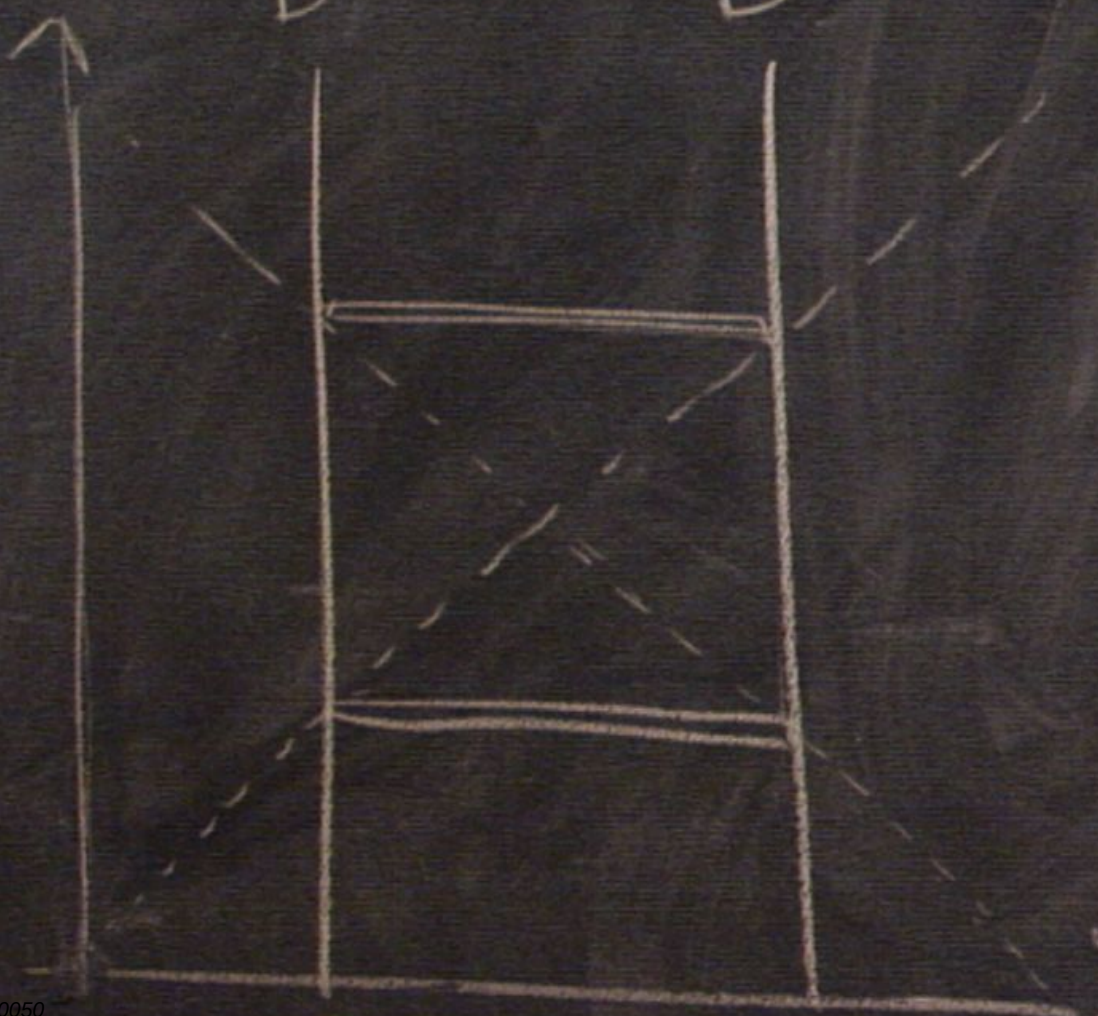
understand P2'



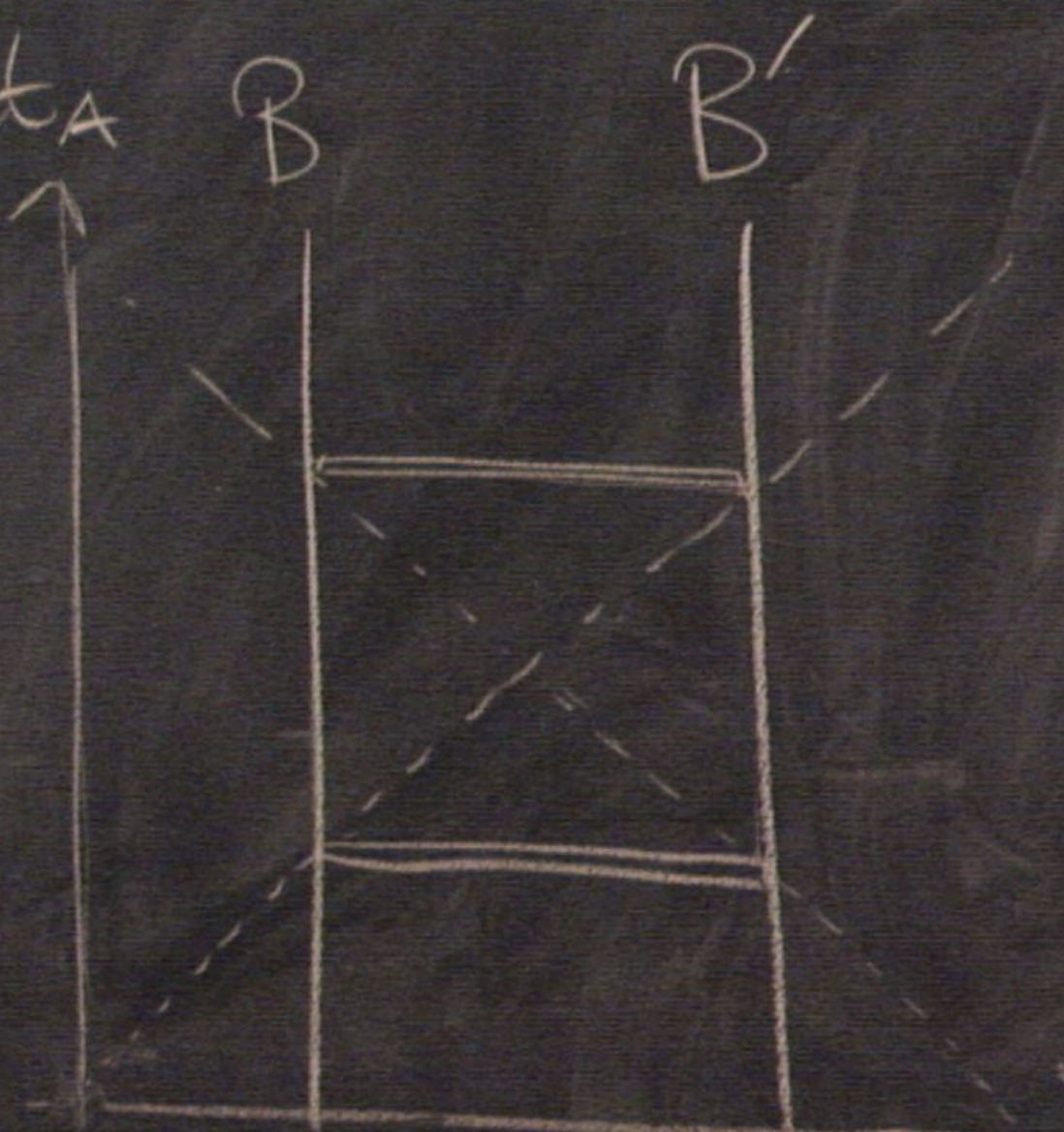
understand P2'

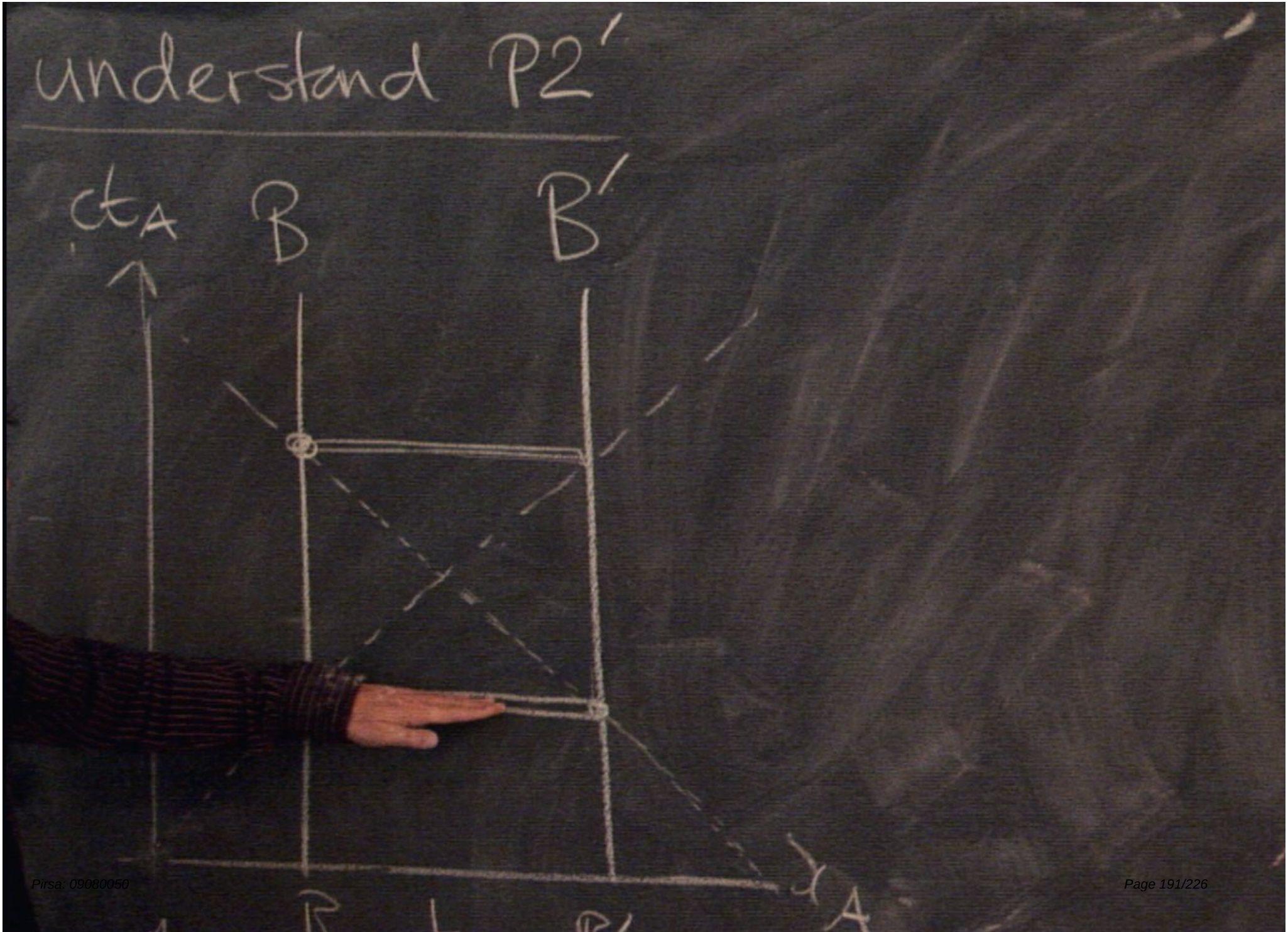


understand P2'

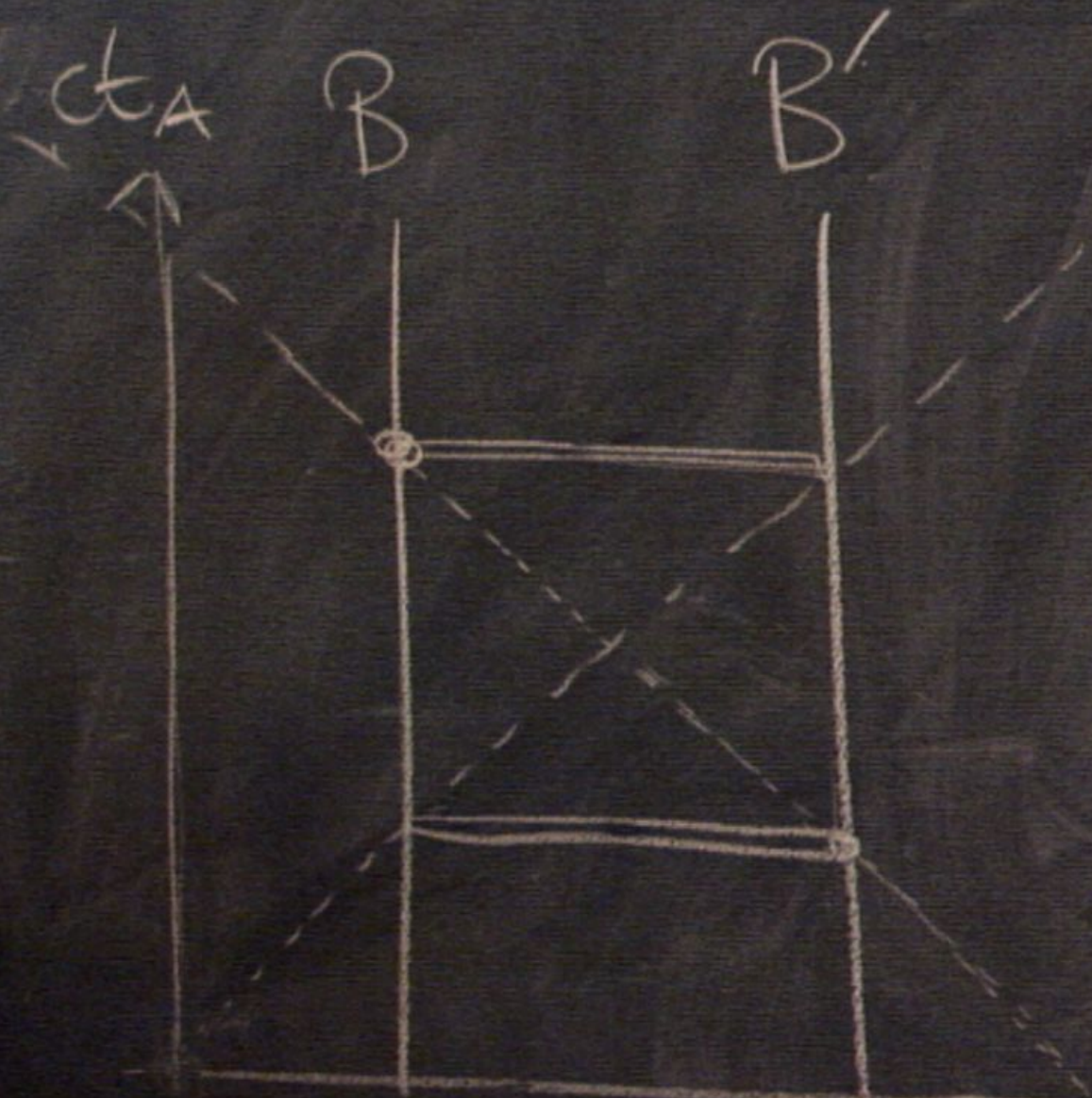


understand P2'

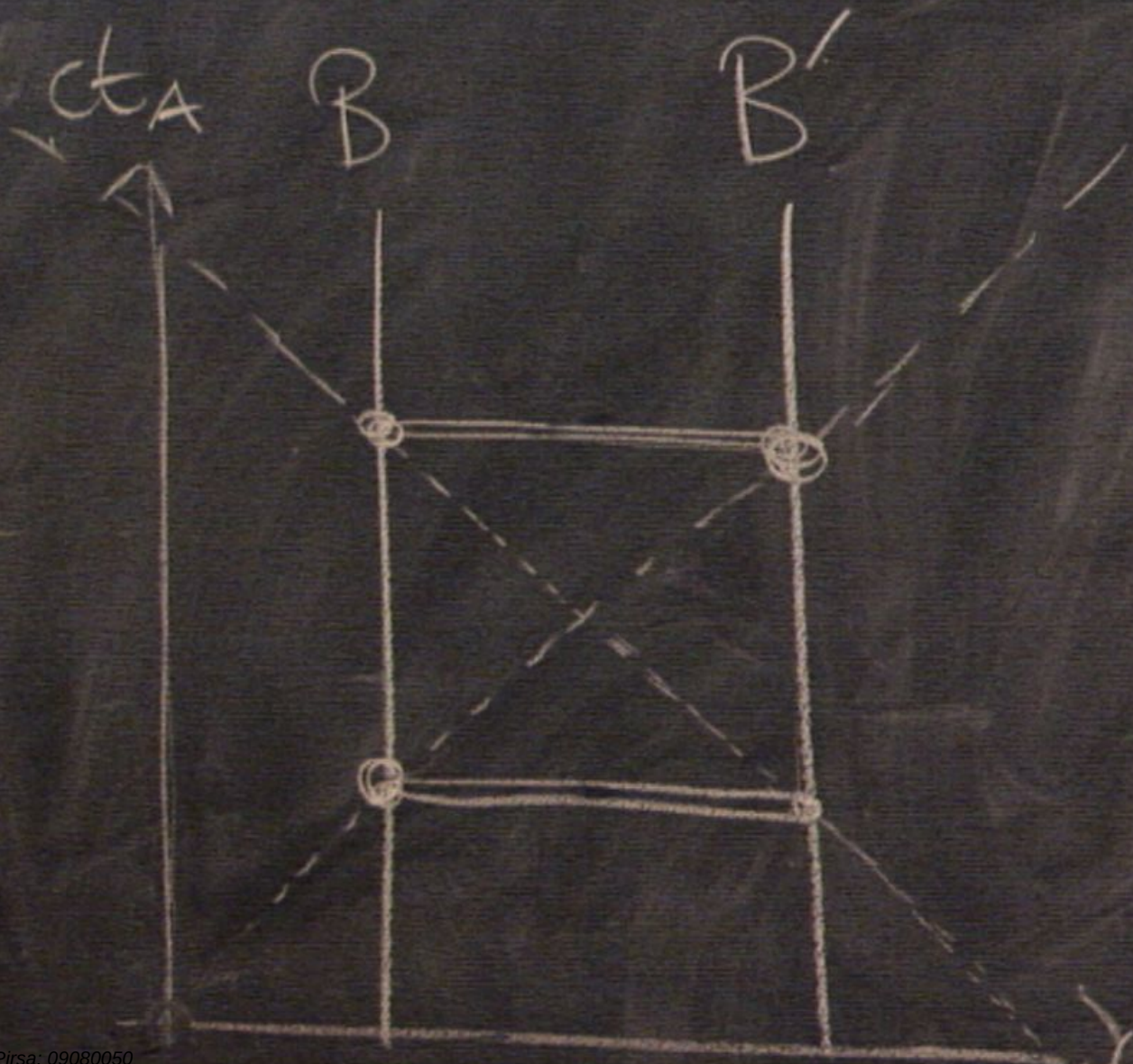


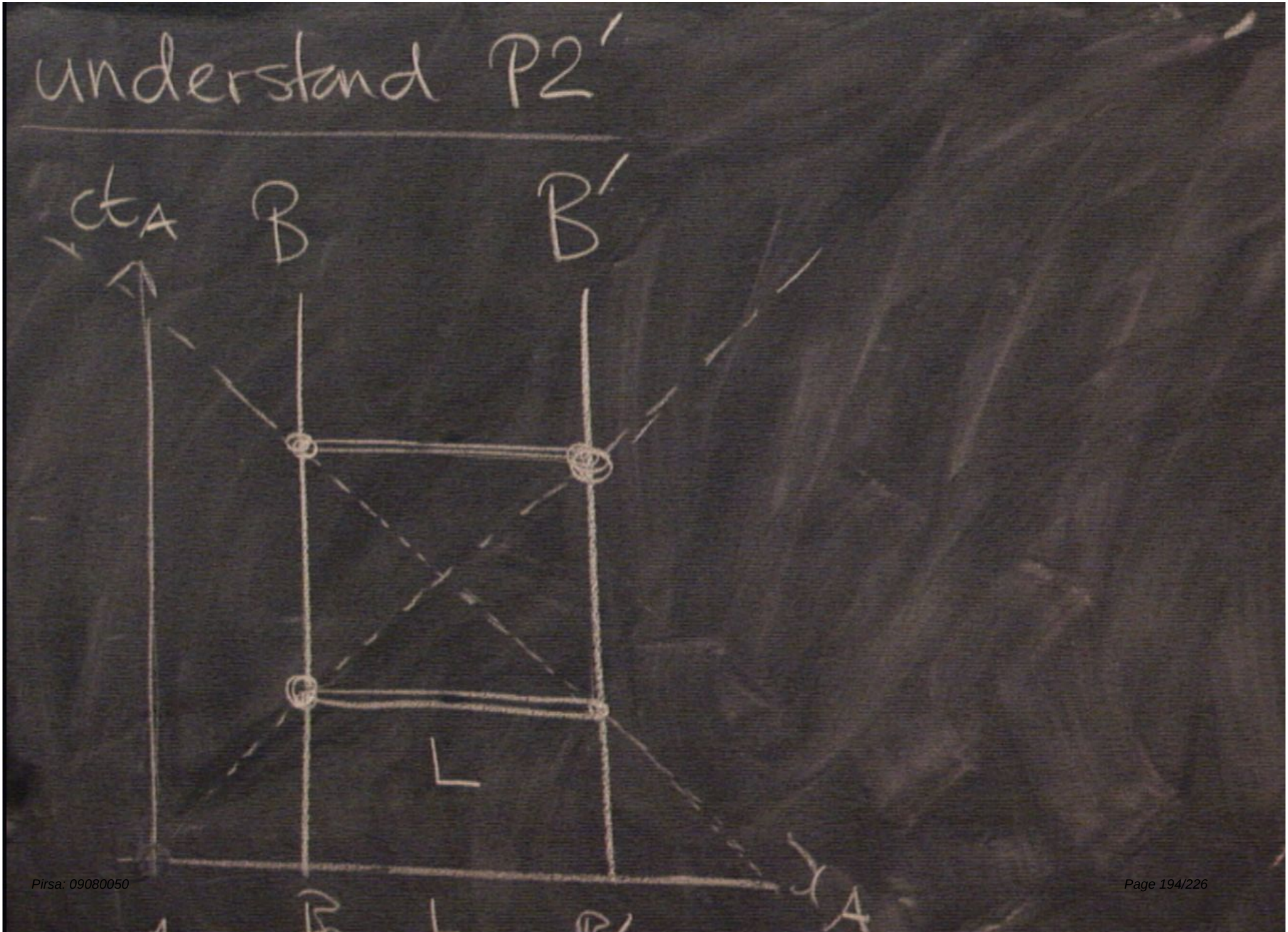

understand P2'
ct_A
B
B'
A

understand P2'

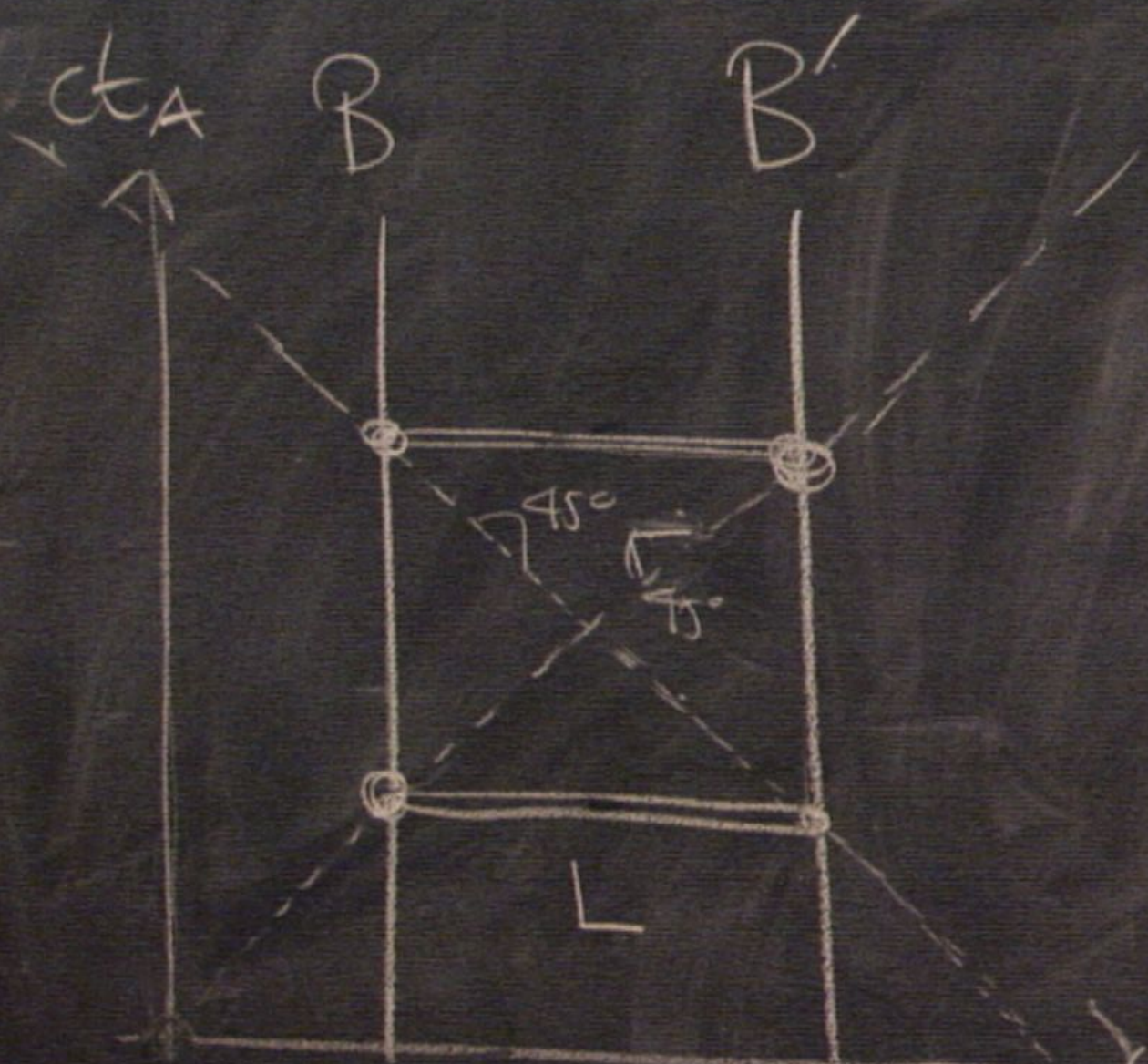


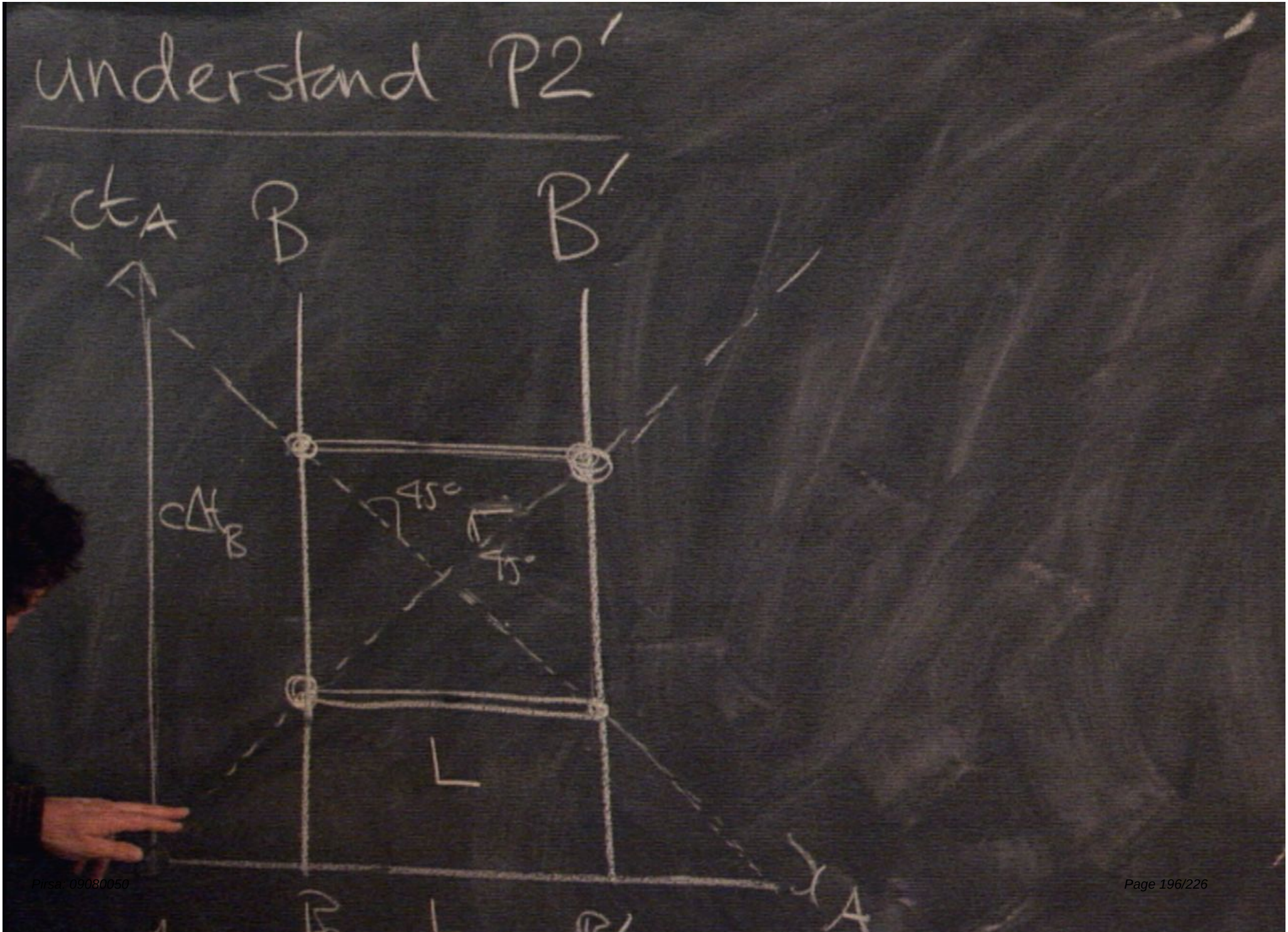
understand P2'

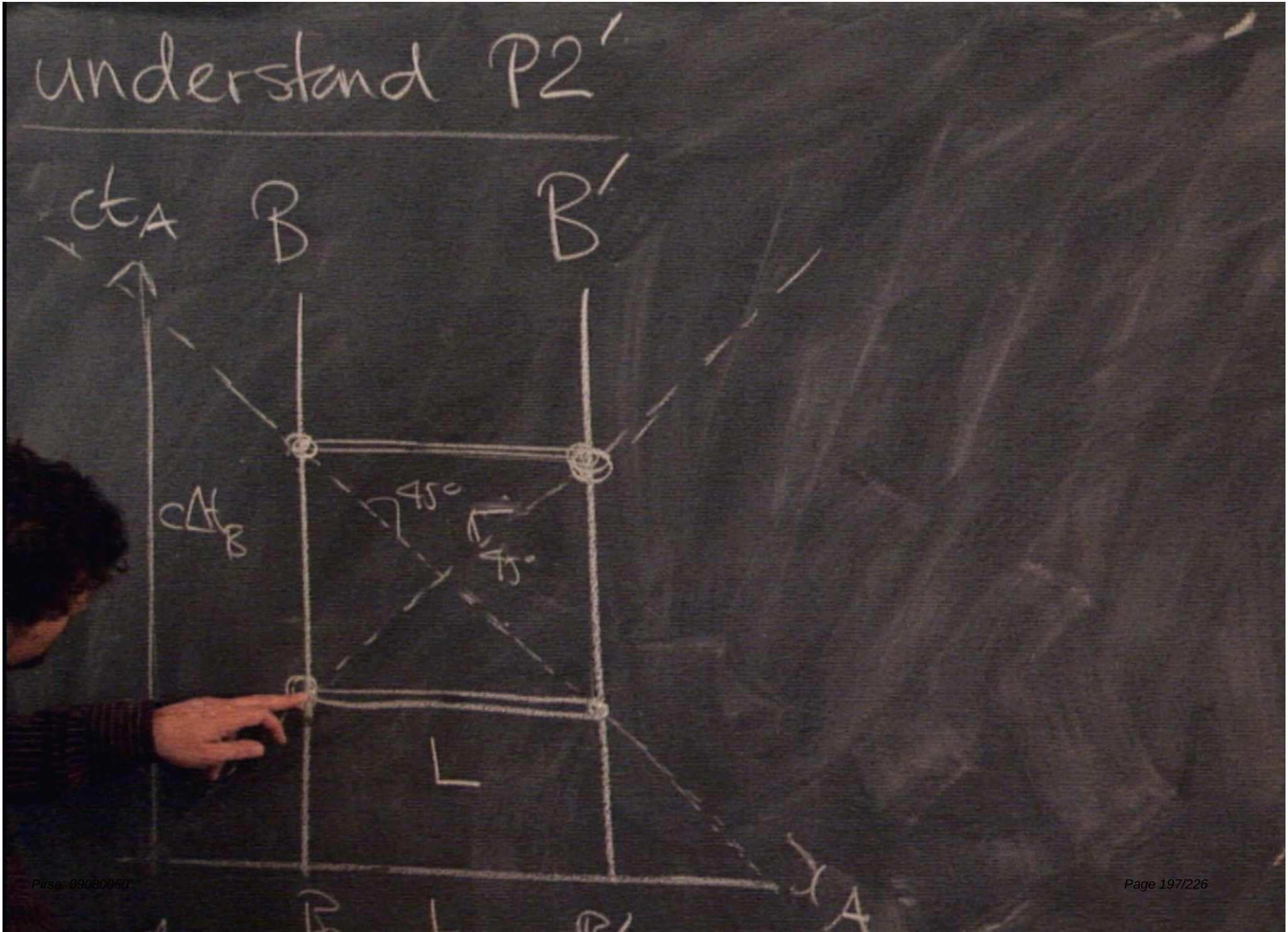



understand P2'
ct_A
B
B'
L
A

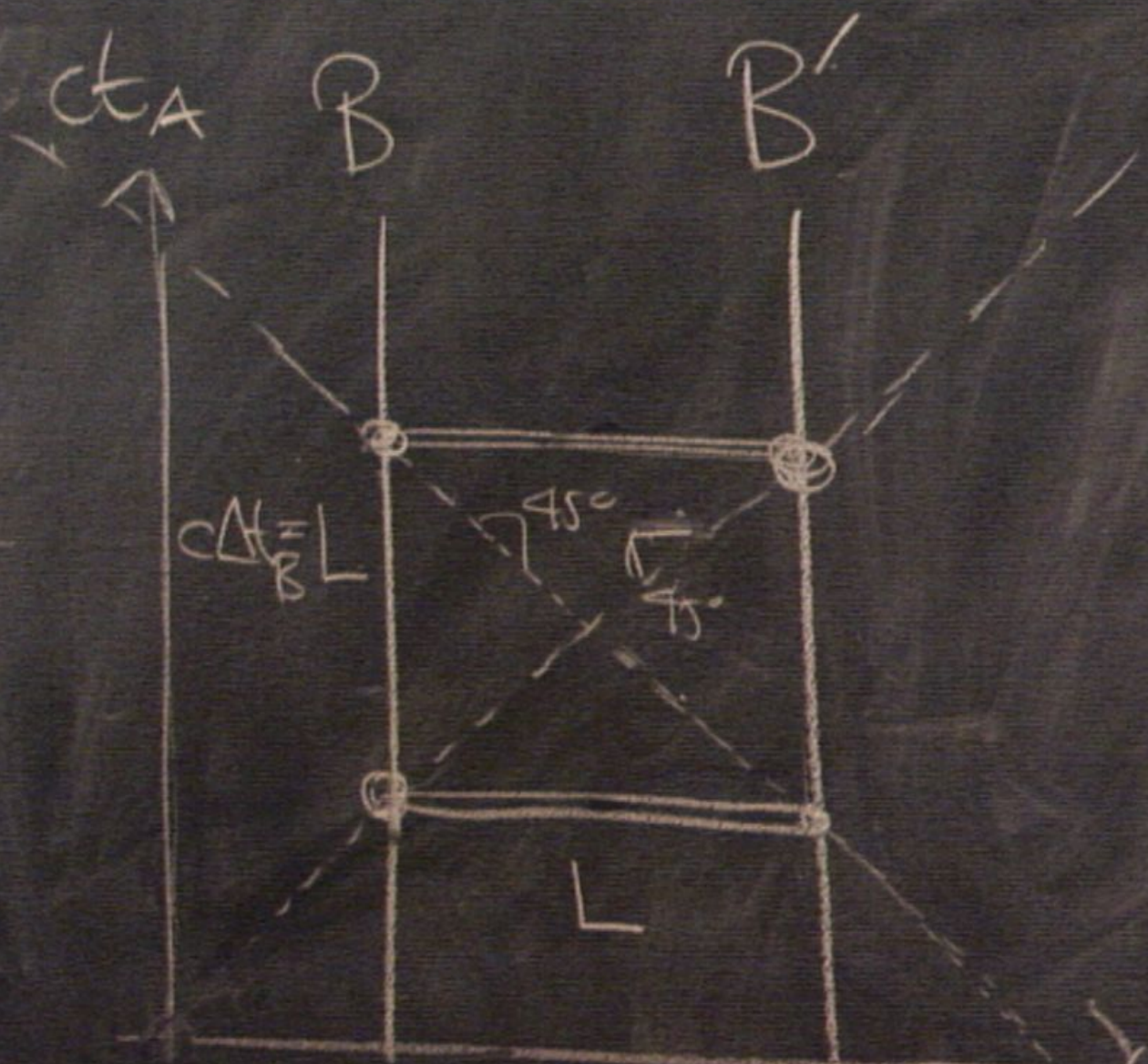
understand P2'



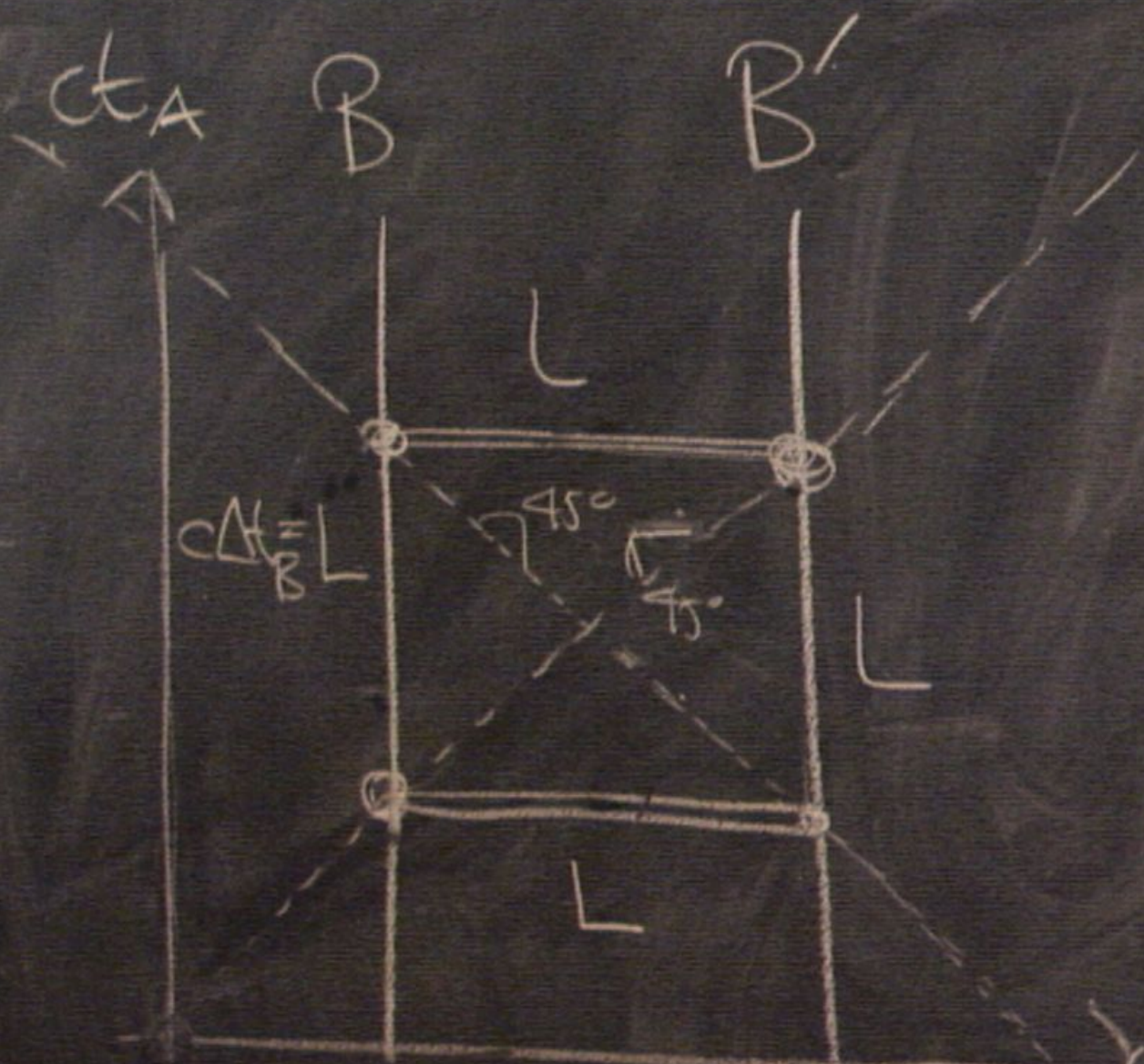

understand P2'
ct_A
B
B'
cΔt_B
45°
45°
L
A

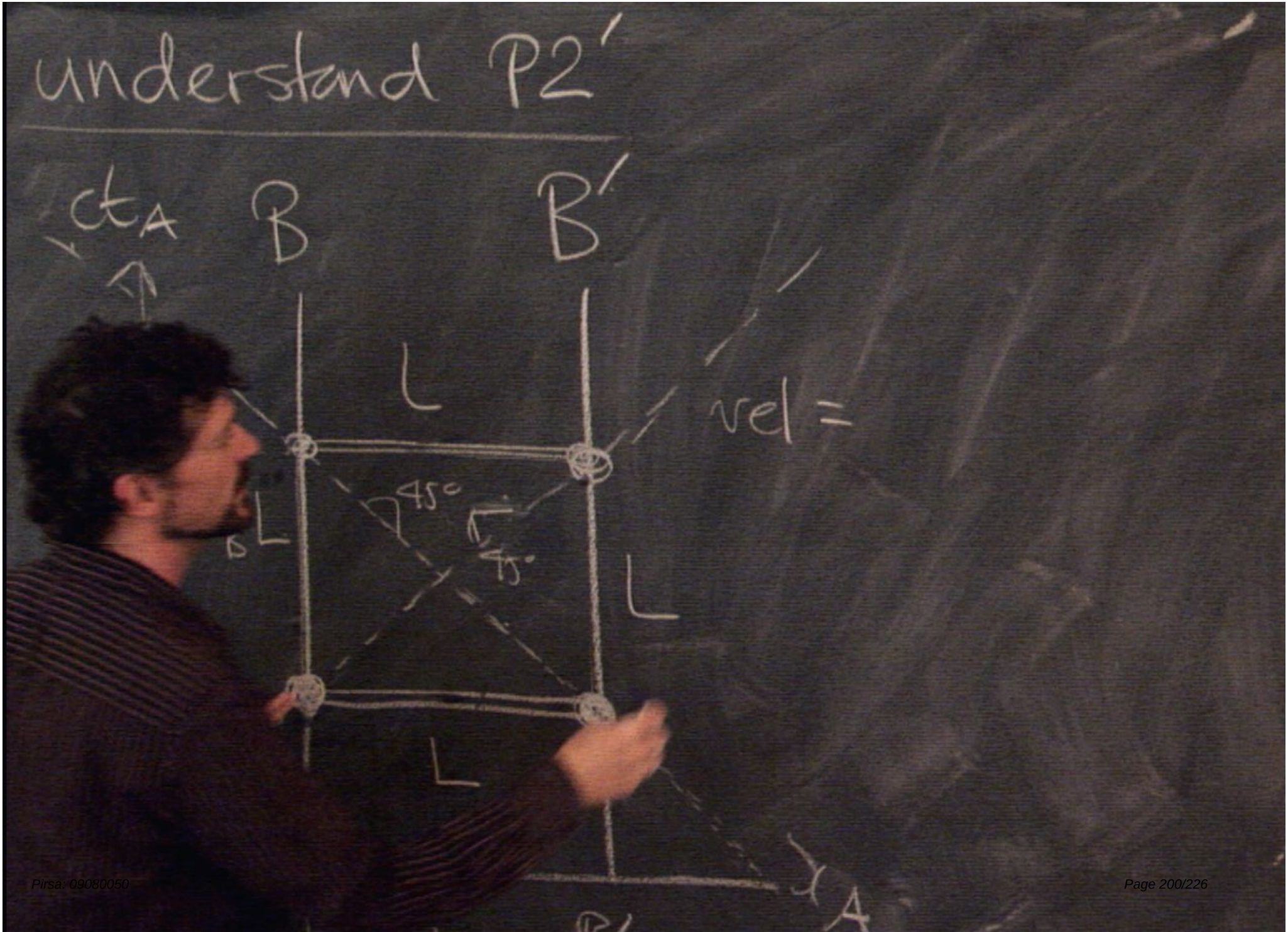

understand P2'
ct_A
B
B'
cΔt_B
45°
45°
L
A

understand P2'

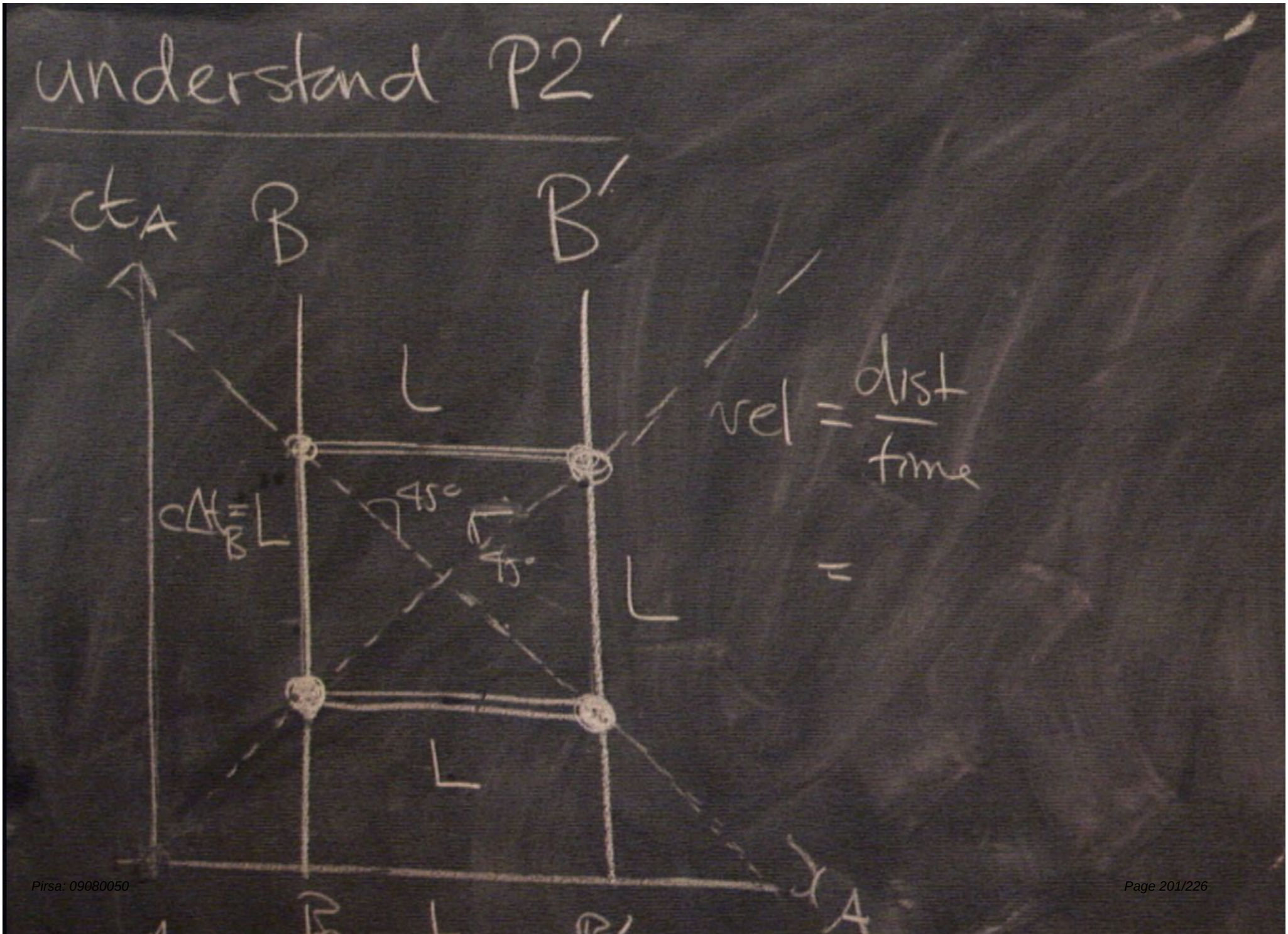


understand P2'

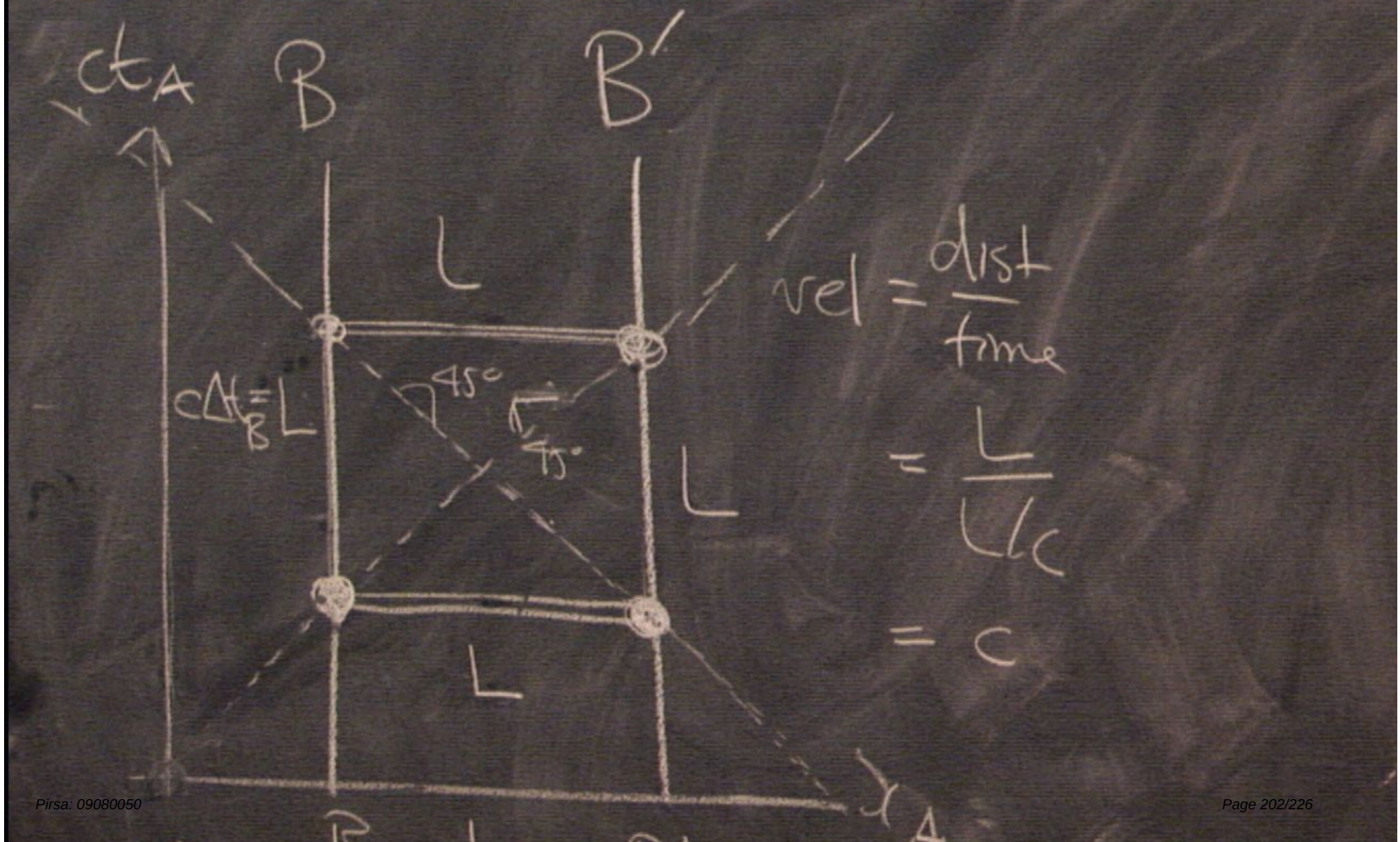



understand P2'
ct_A
B
B'
L
vel =
45°
45°
L
L
L
A

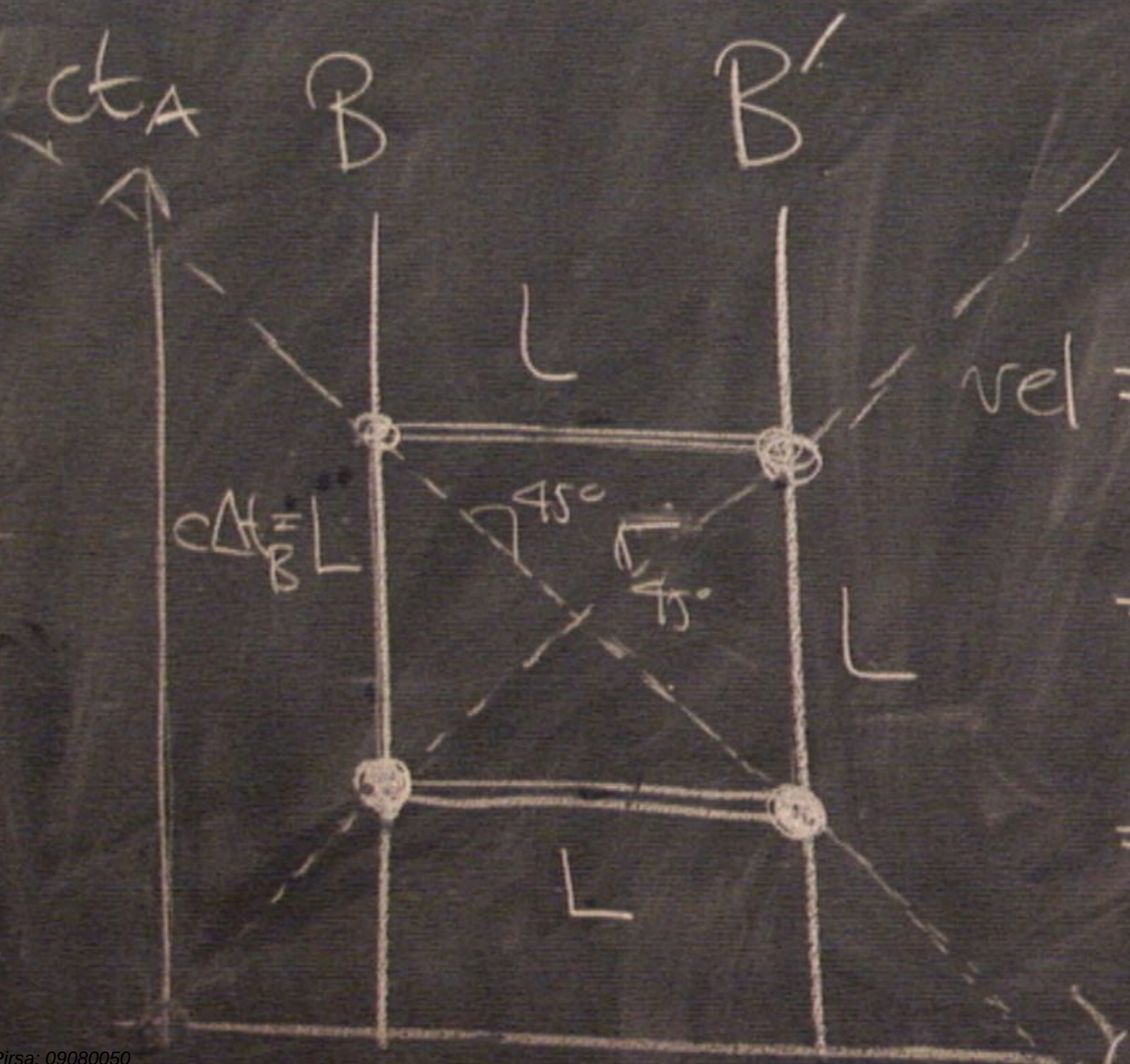
understand P2'



understand P2'



understand P2'



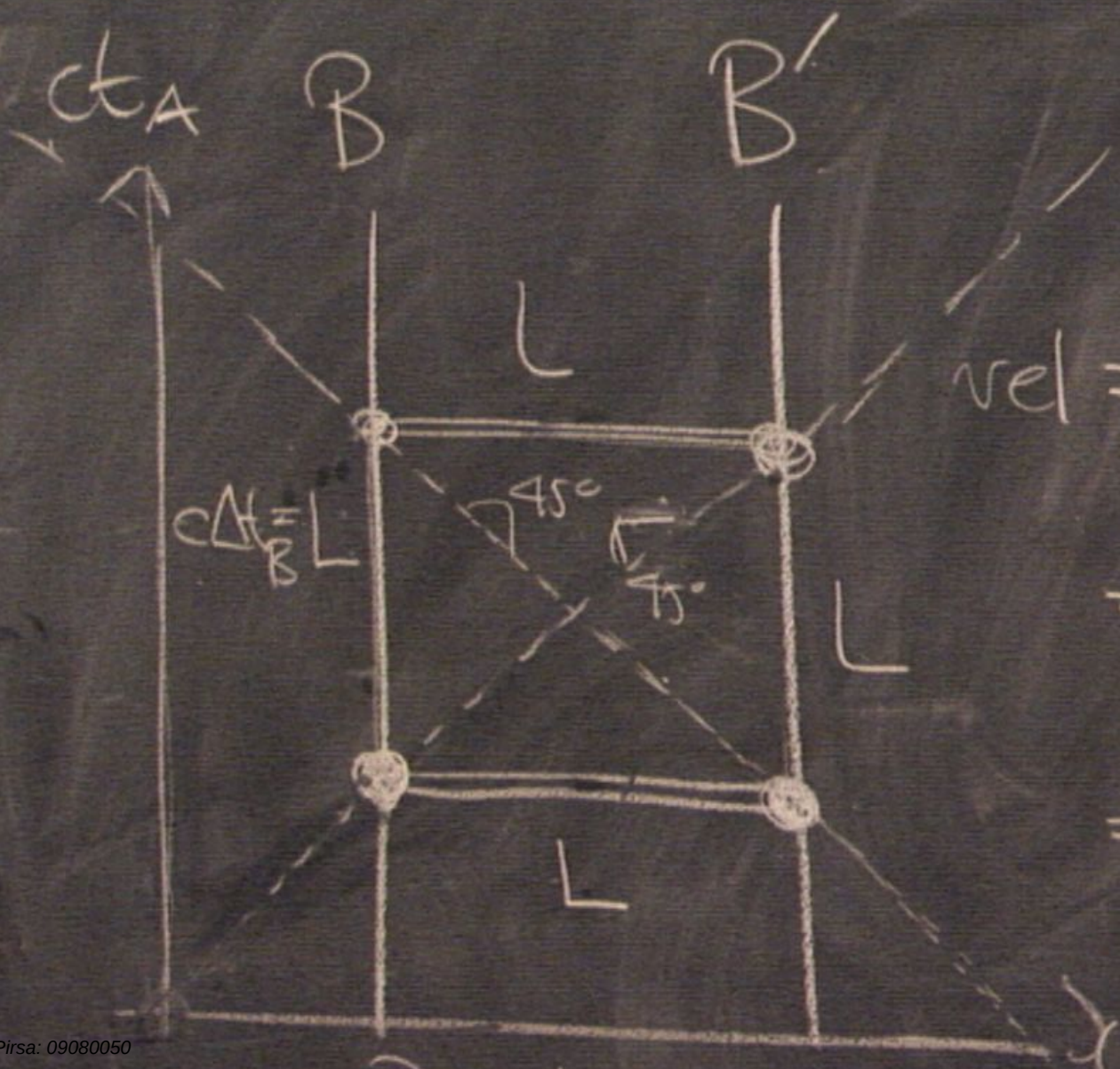
$$vel = \frac{dist}{time}$$

$$= \frac{L}{L/c}$$

$$= c$$

A

understand P2'

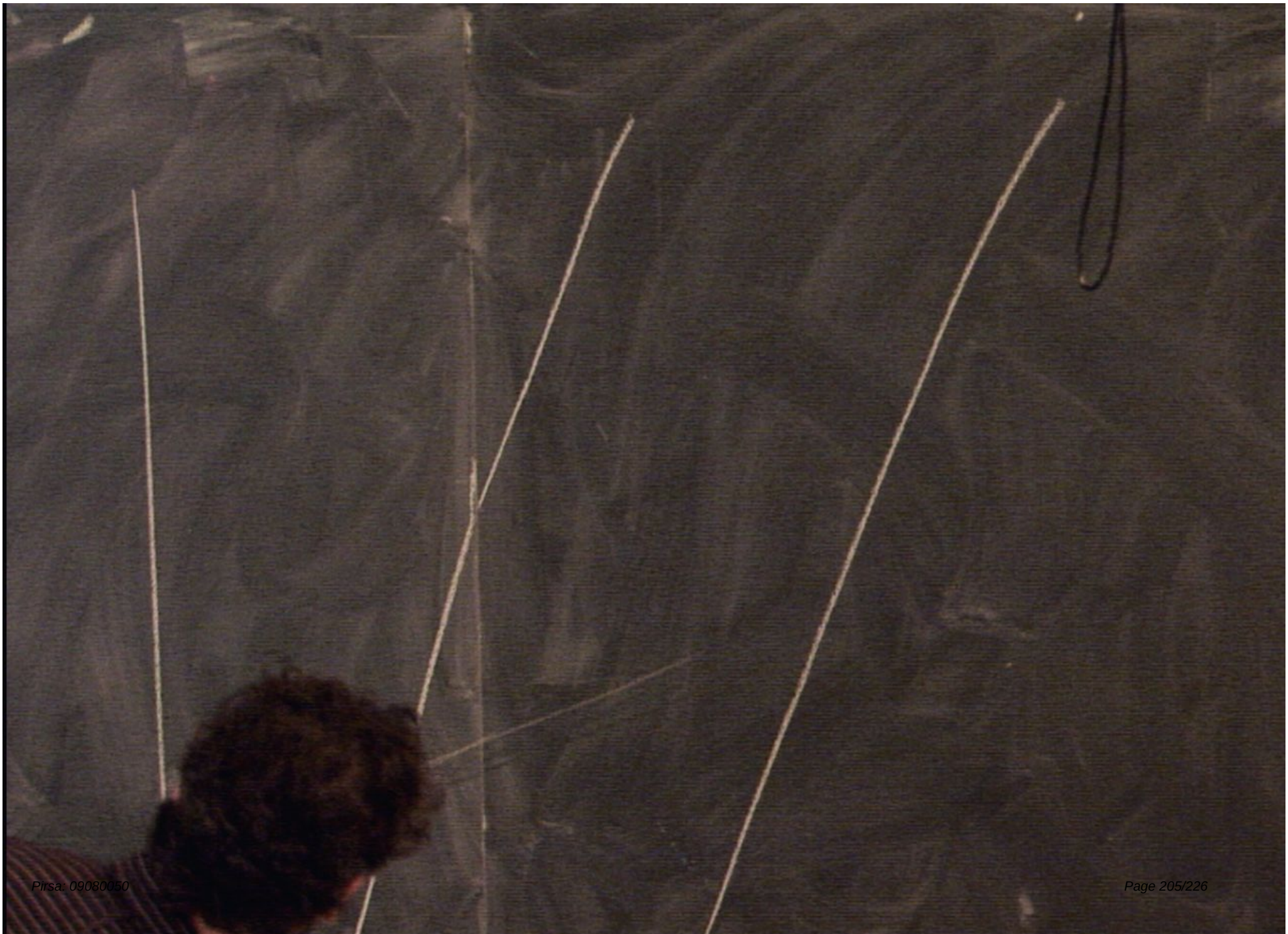


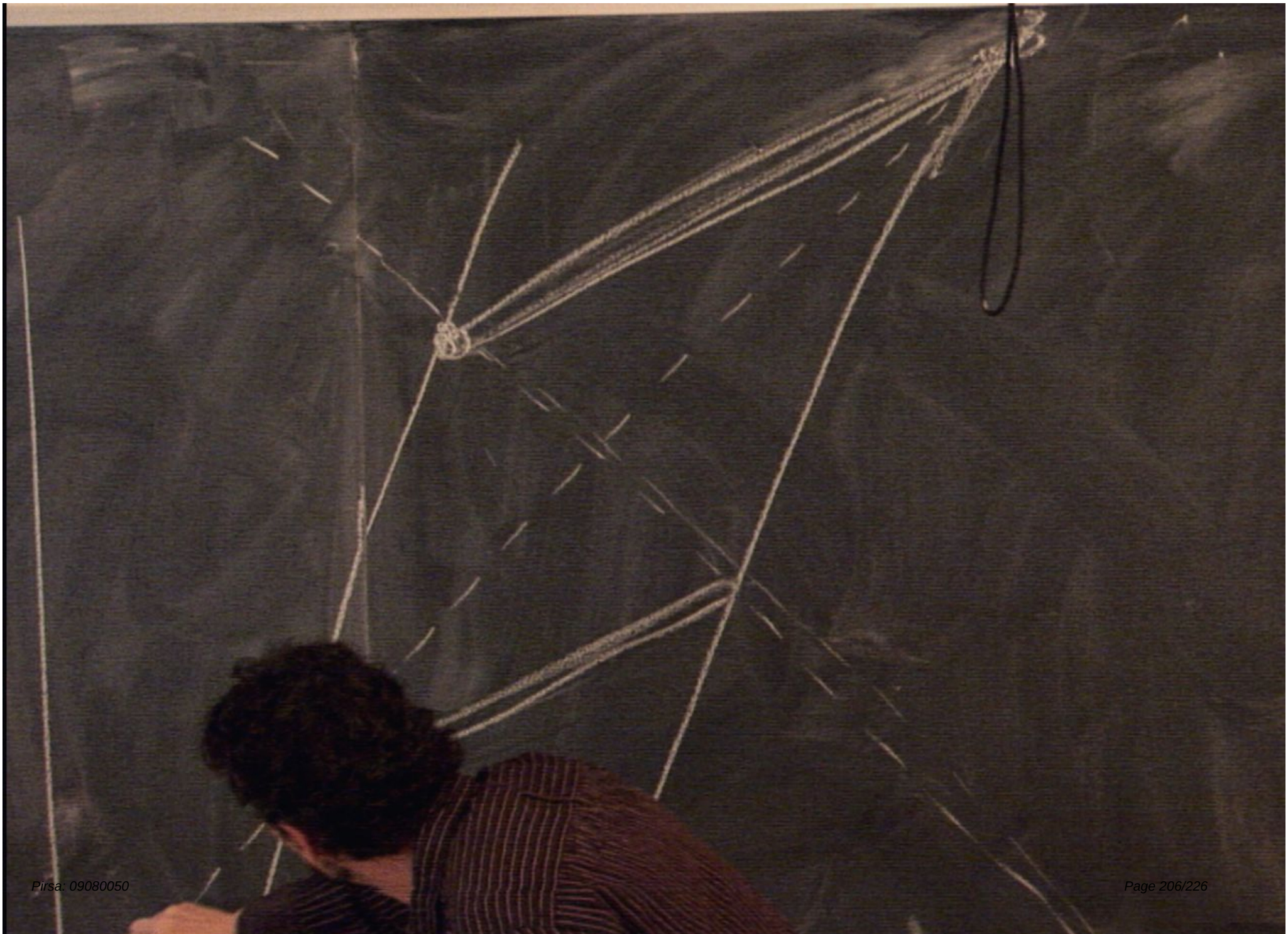
$$vel = \frac{dist}{time}$$

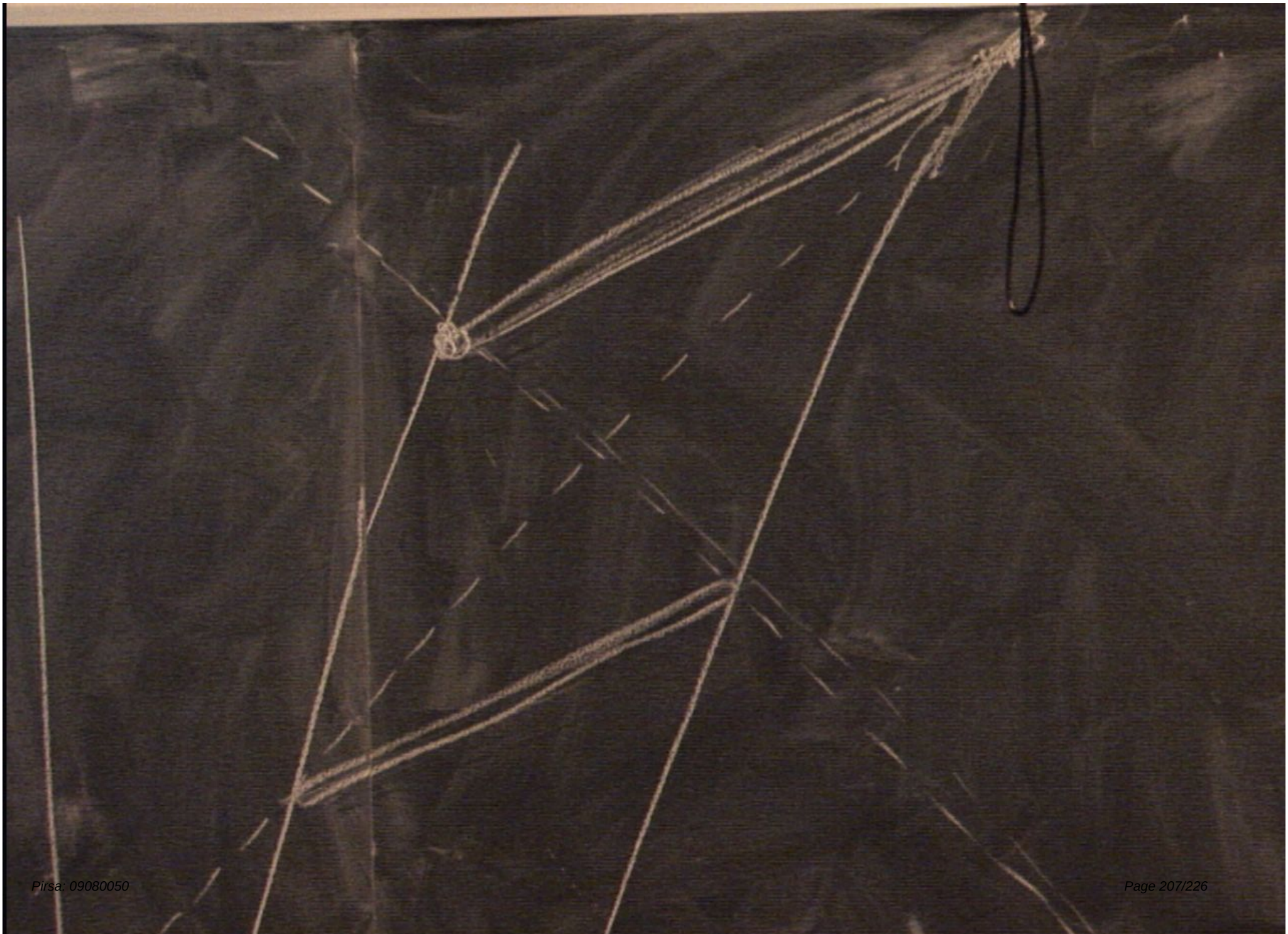
$$= \frac{L}{L/c}$$

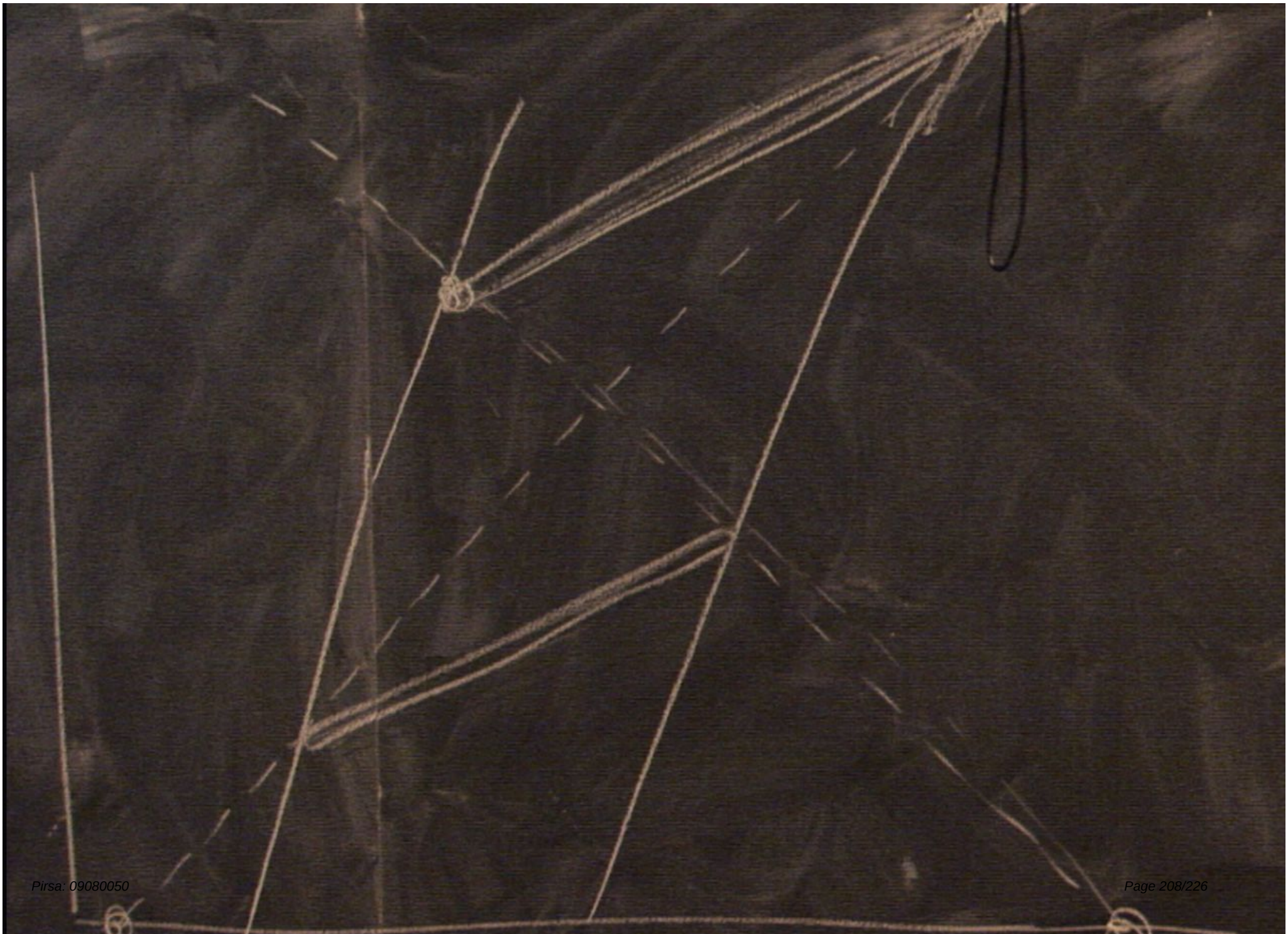
$$= c$$

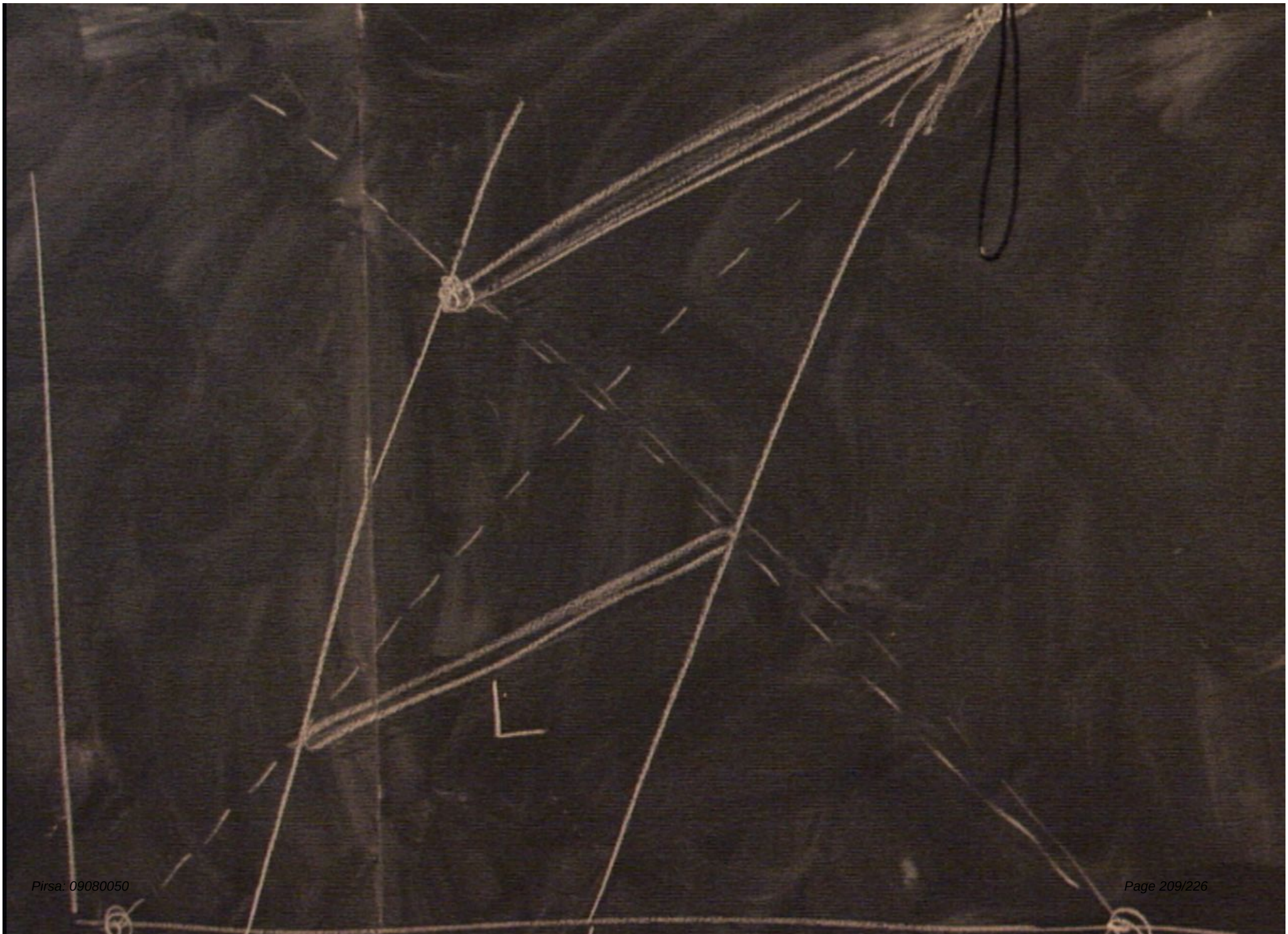
A

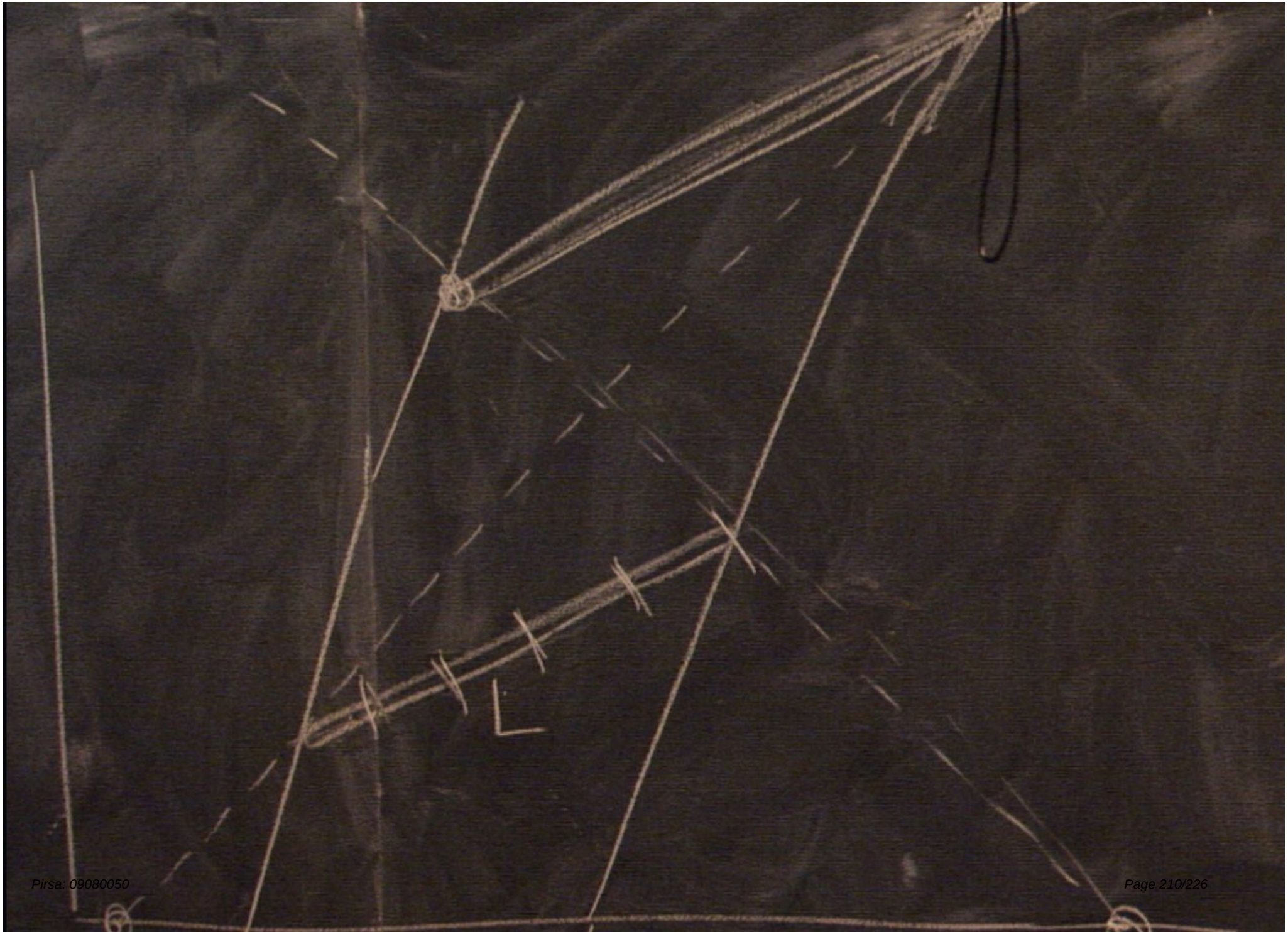


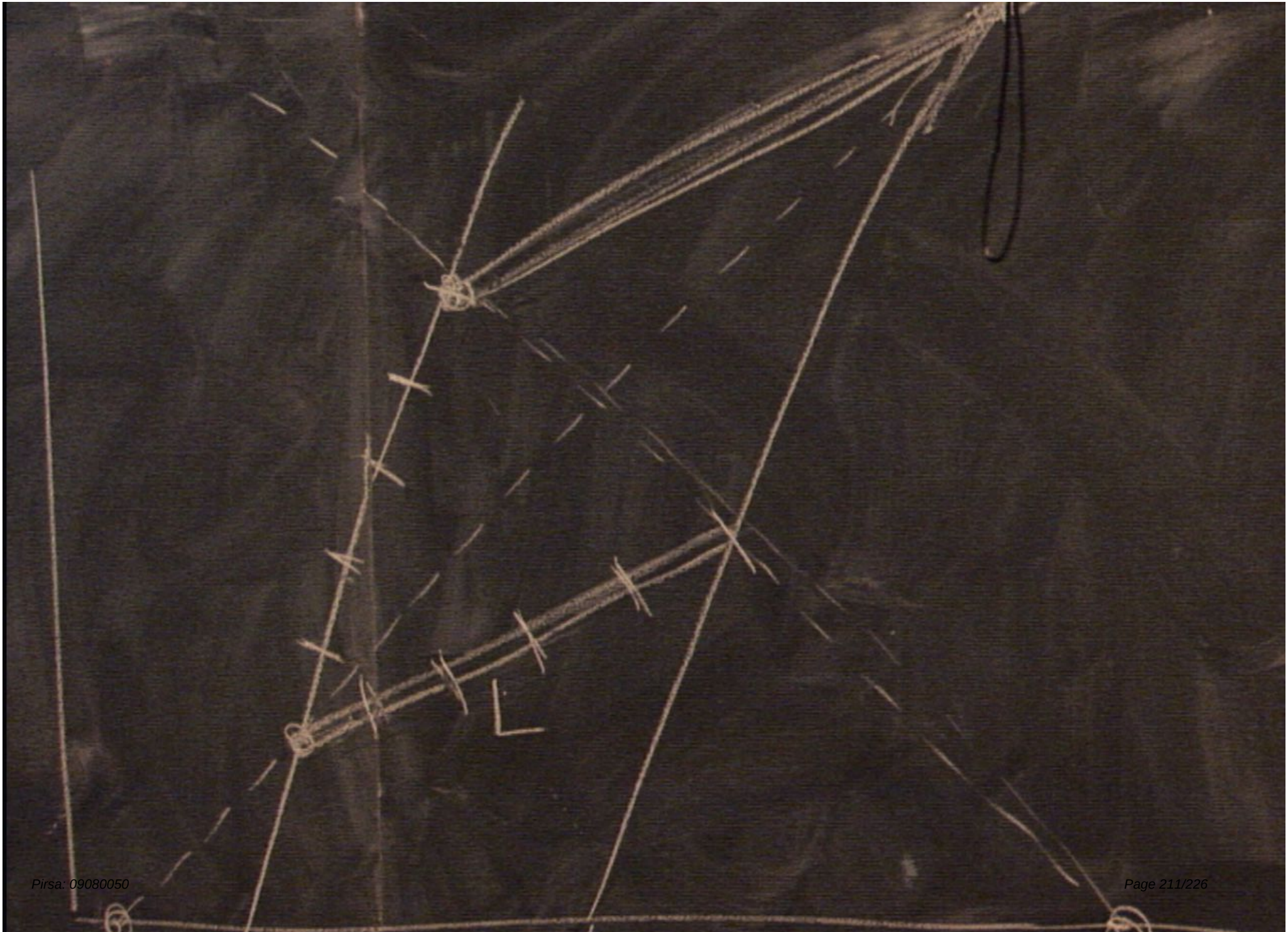


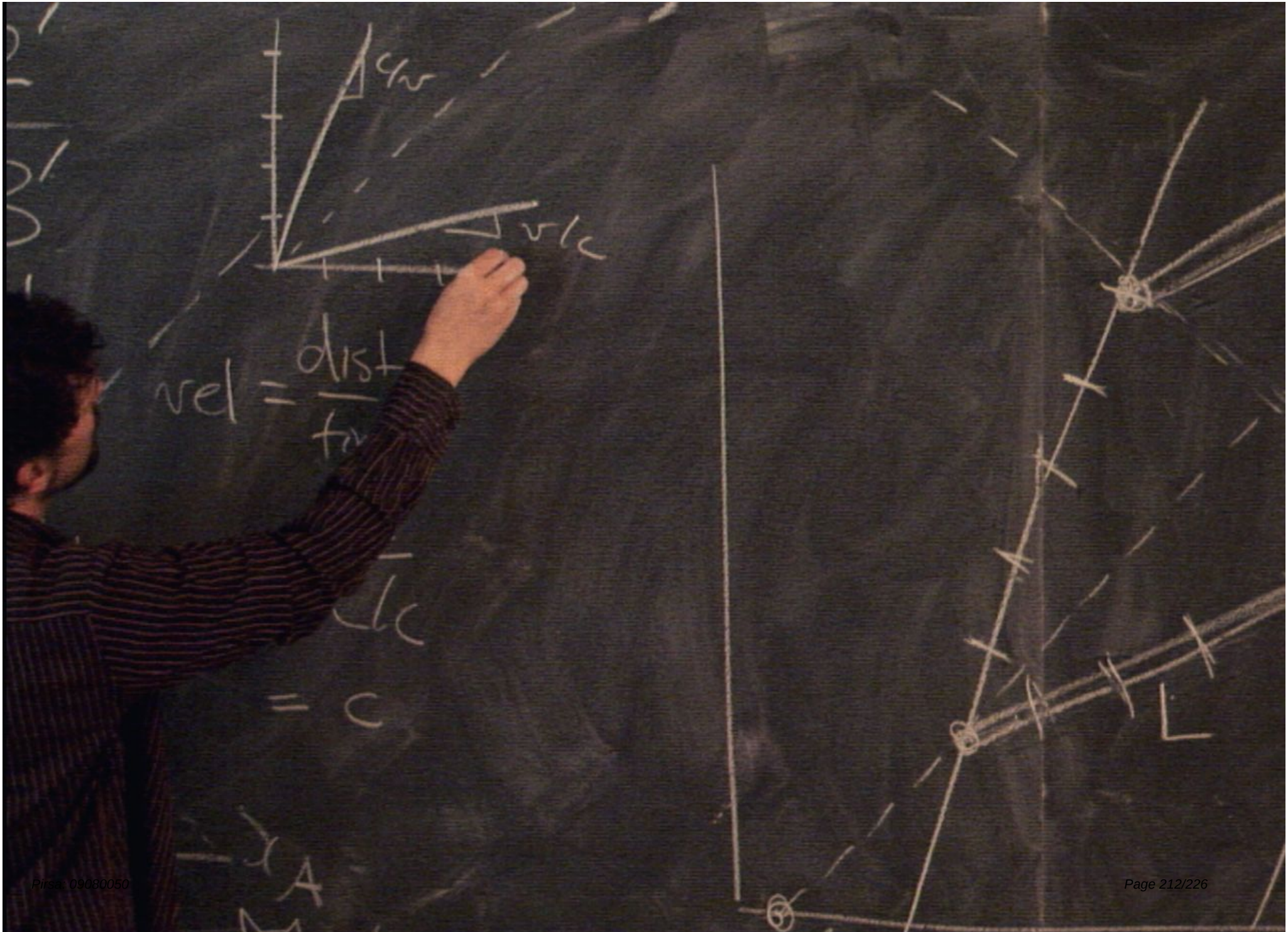


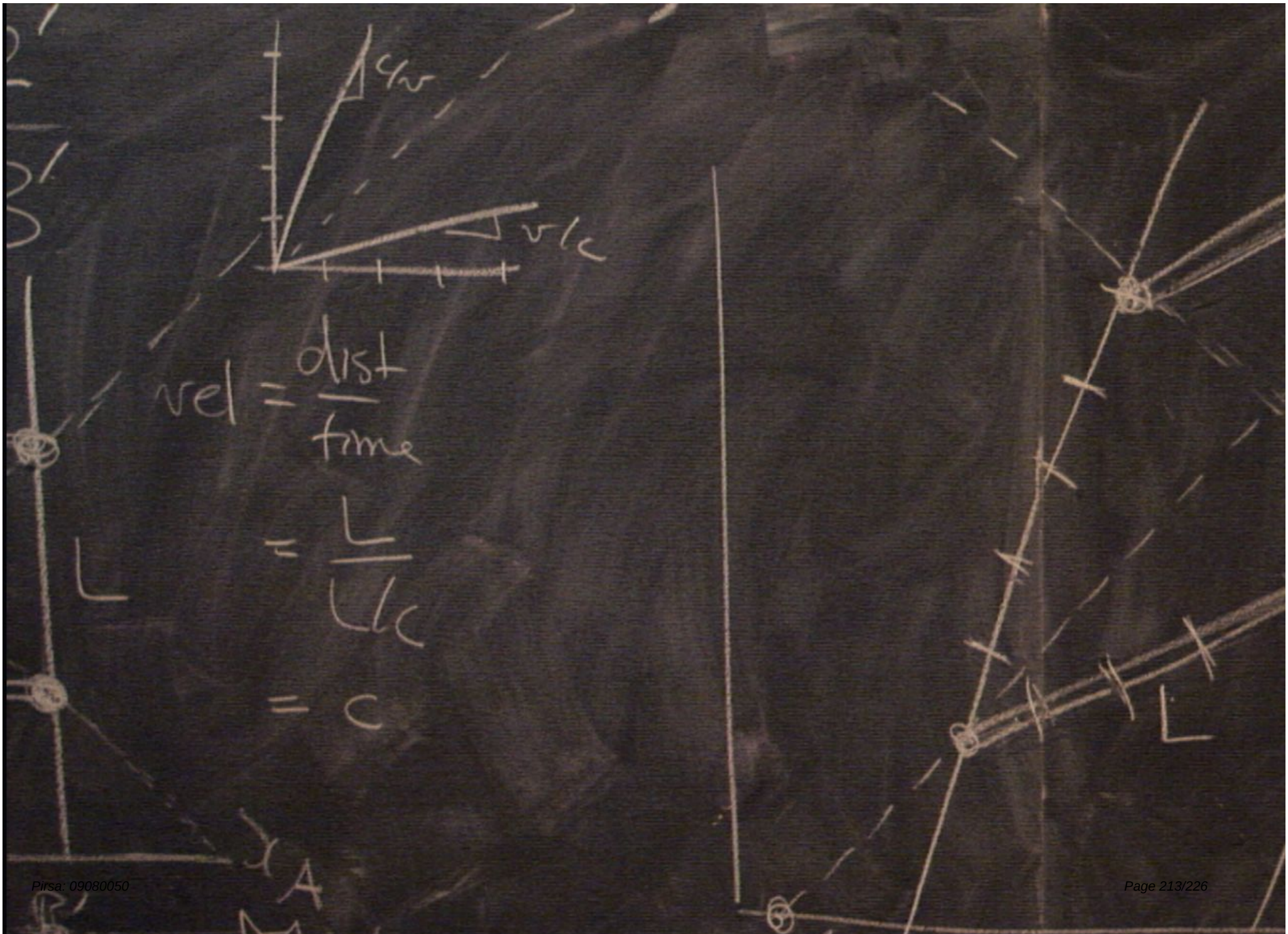


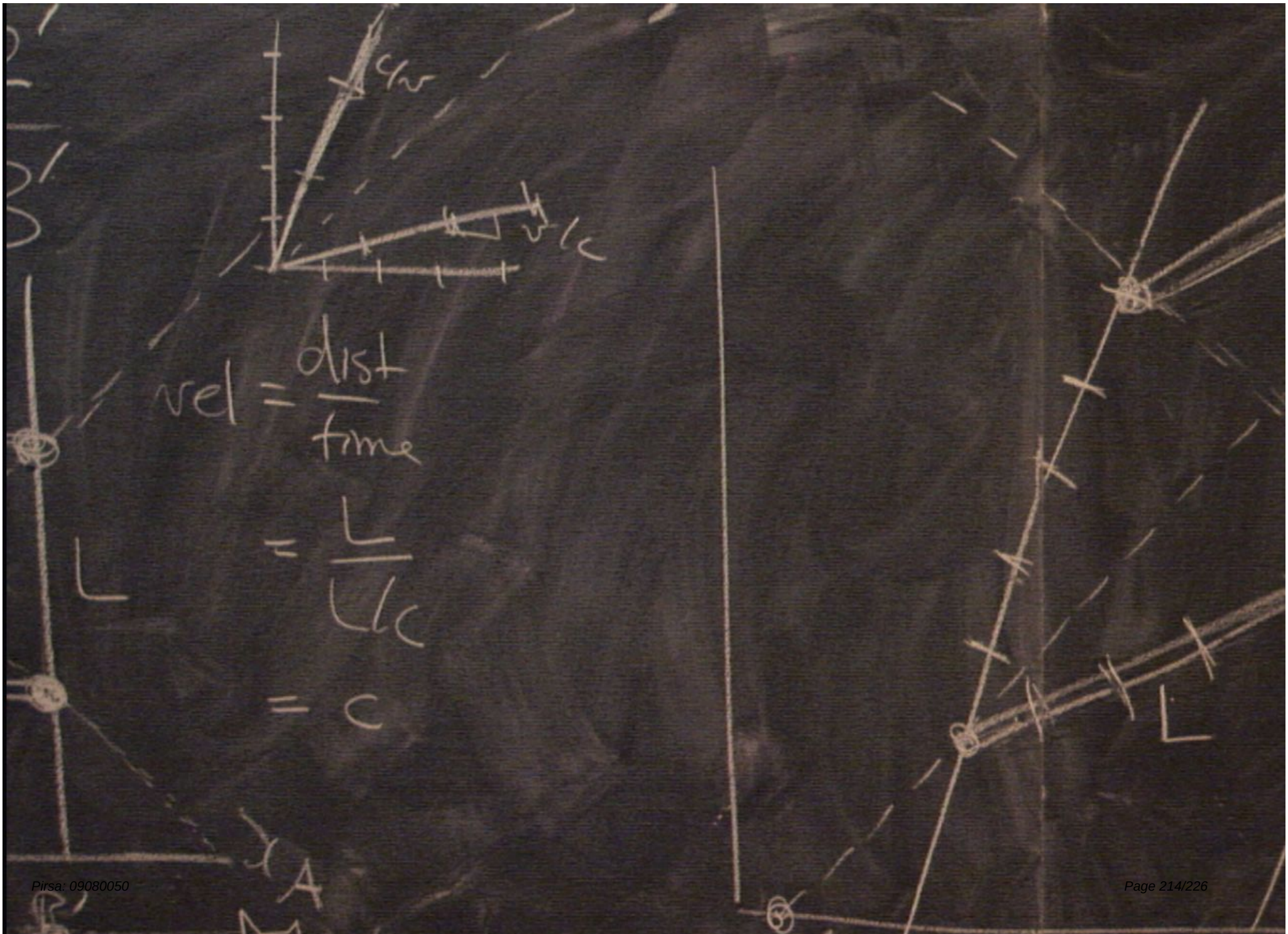


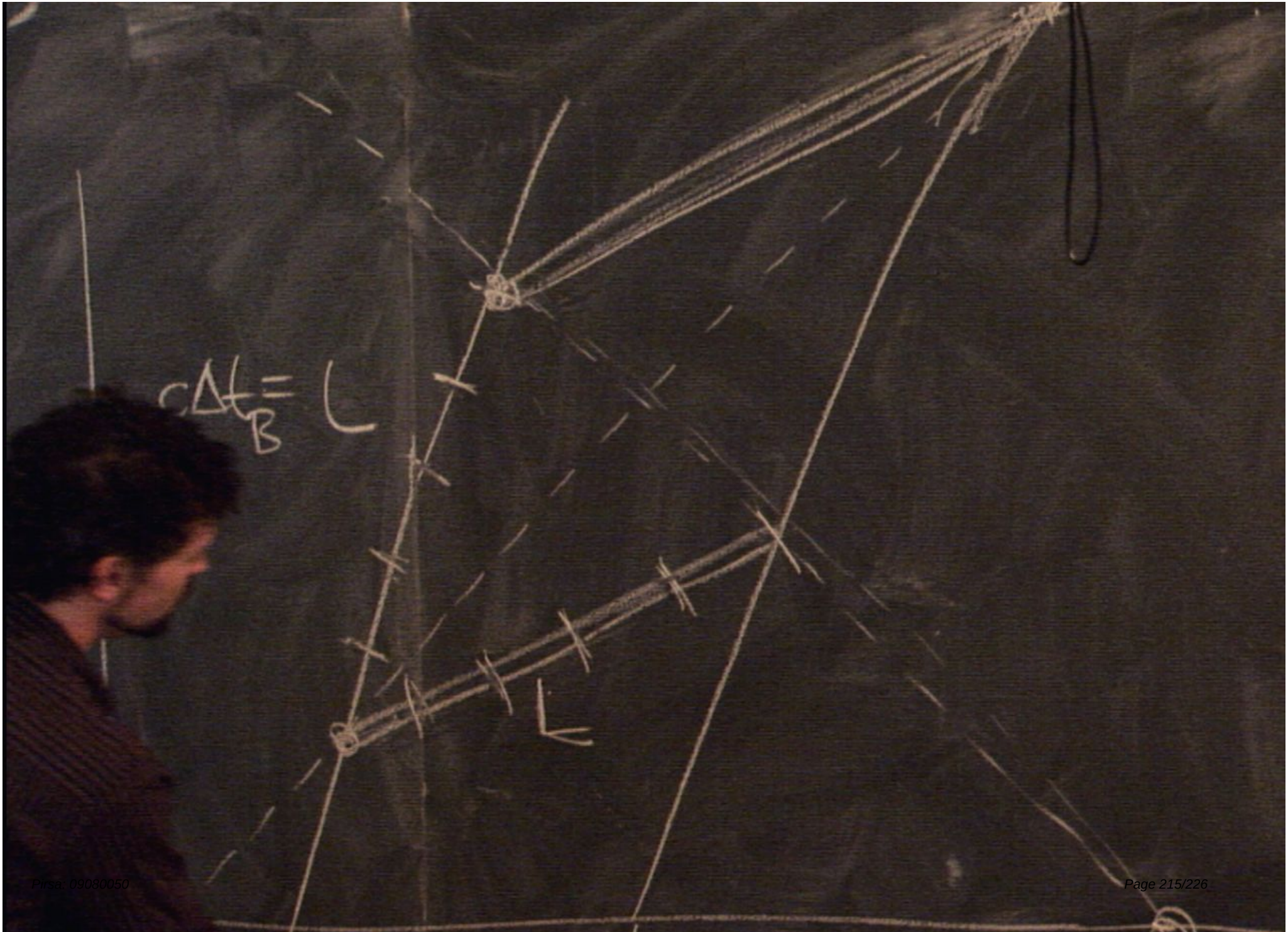


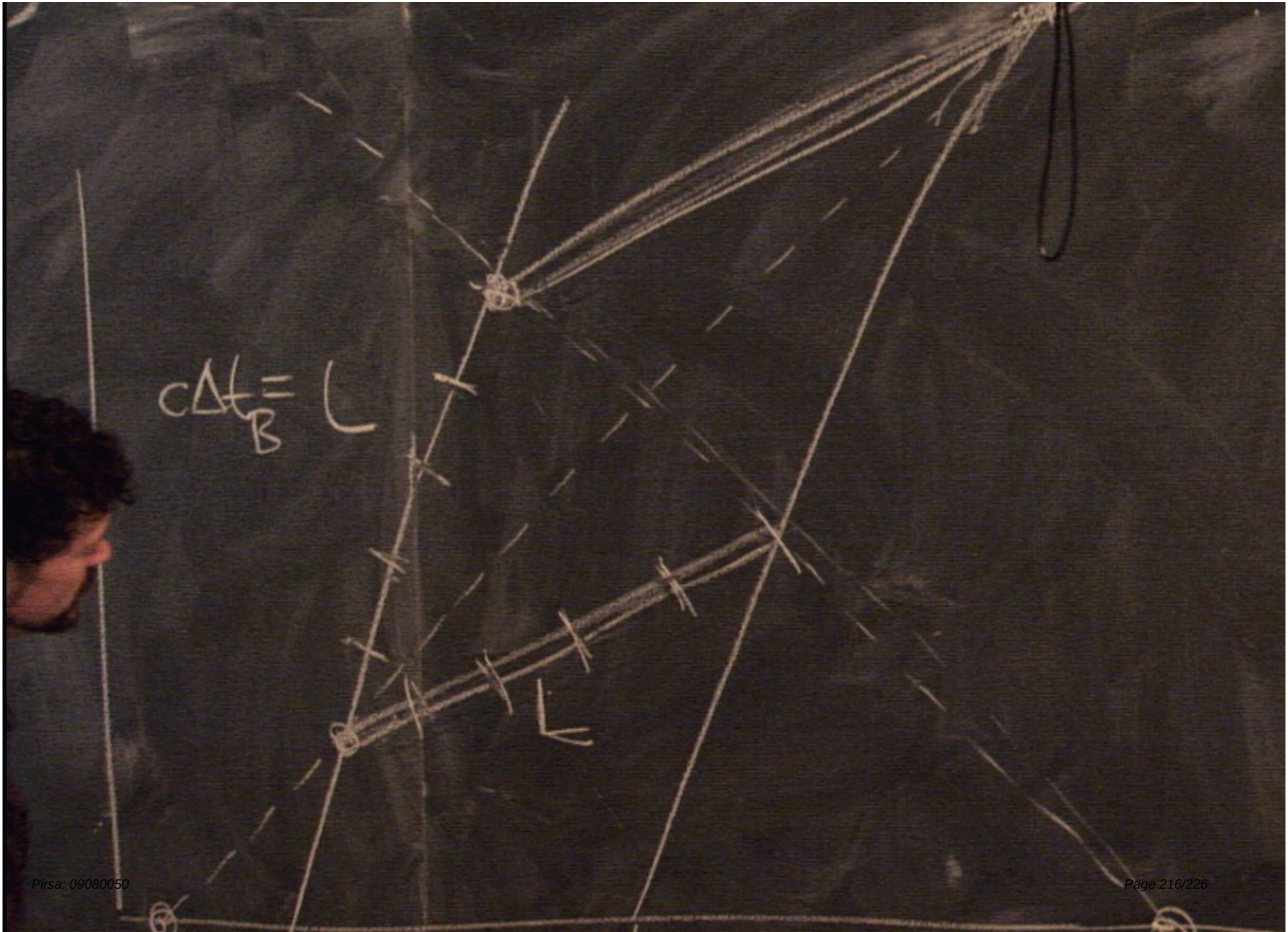


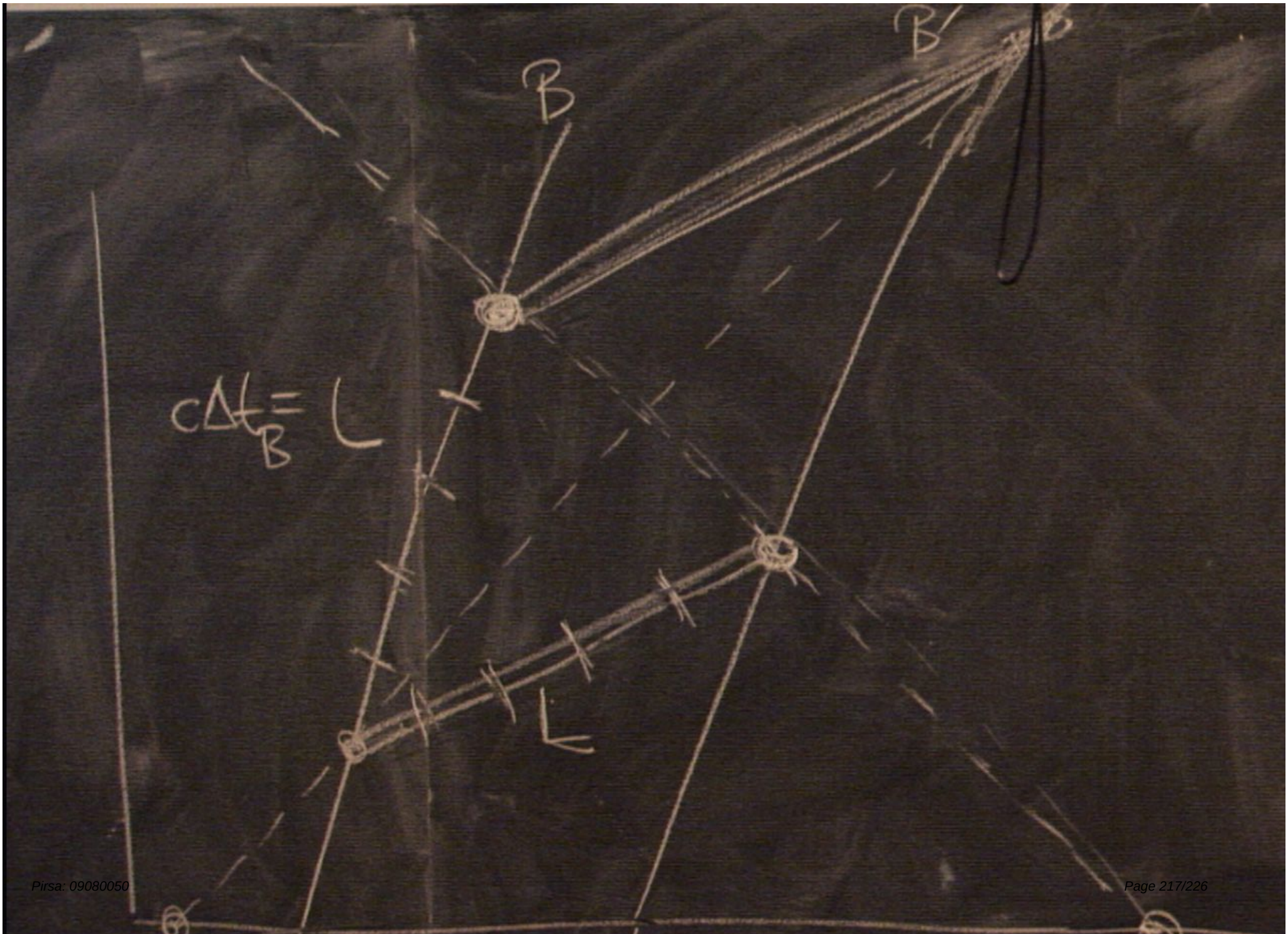

c/v
v/c
vel = dist / t
= c
L

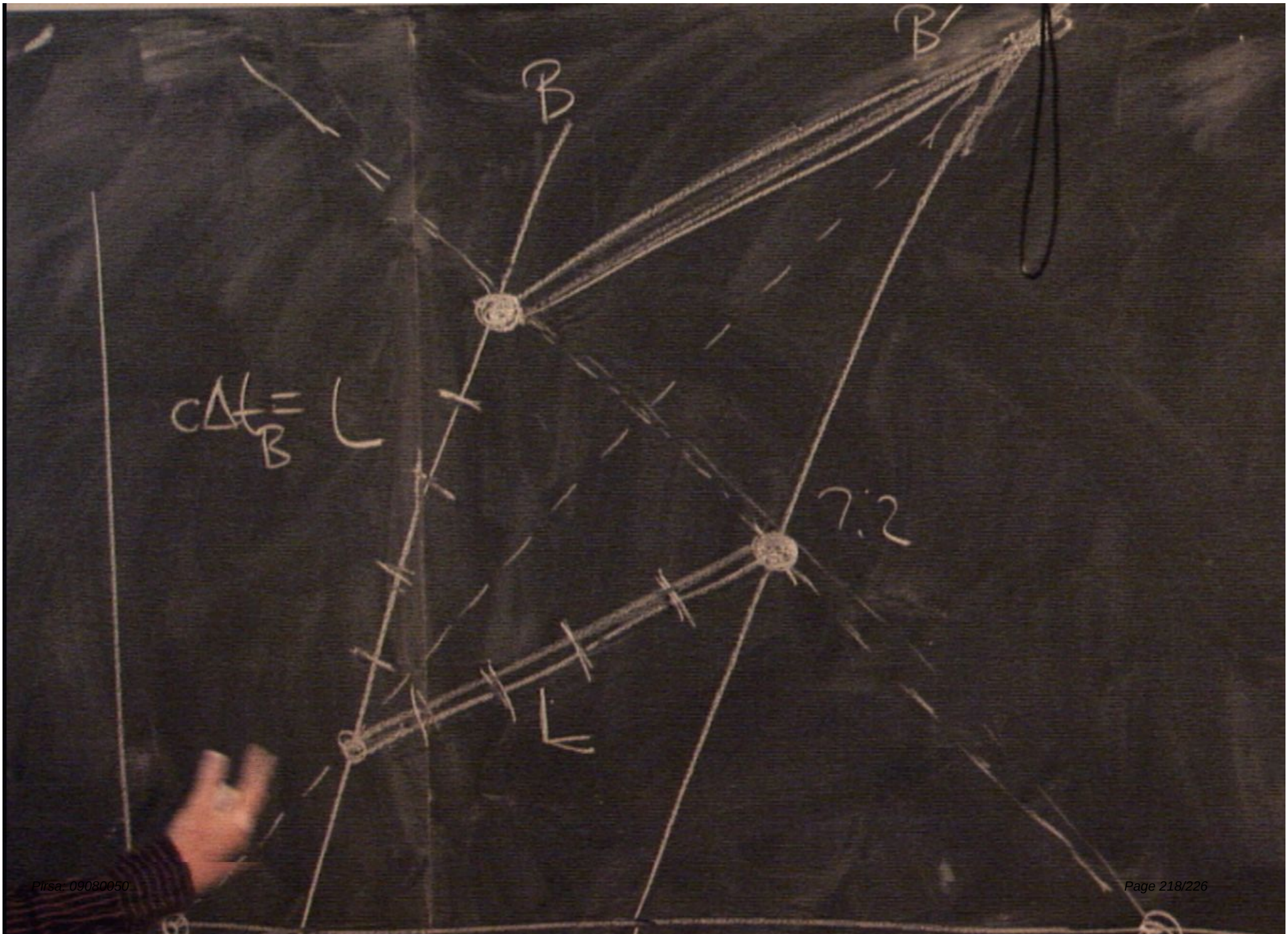

v/c
vel = dist / time
= L / v/c
= c
L
A
B
L

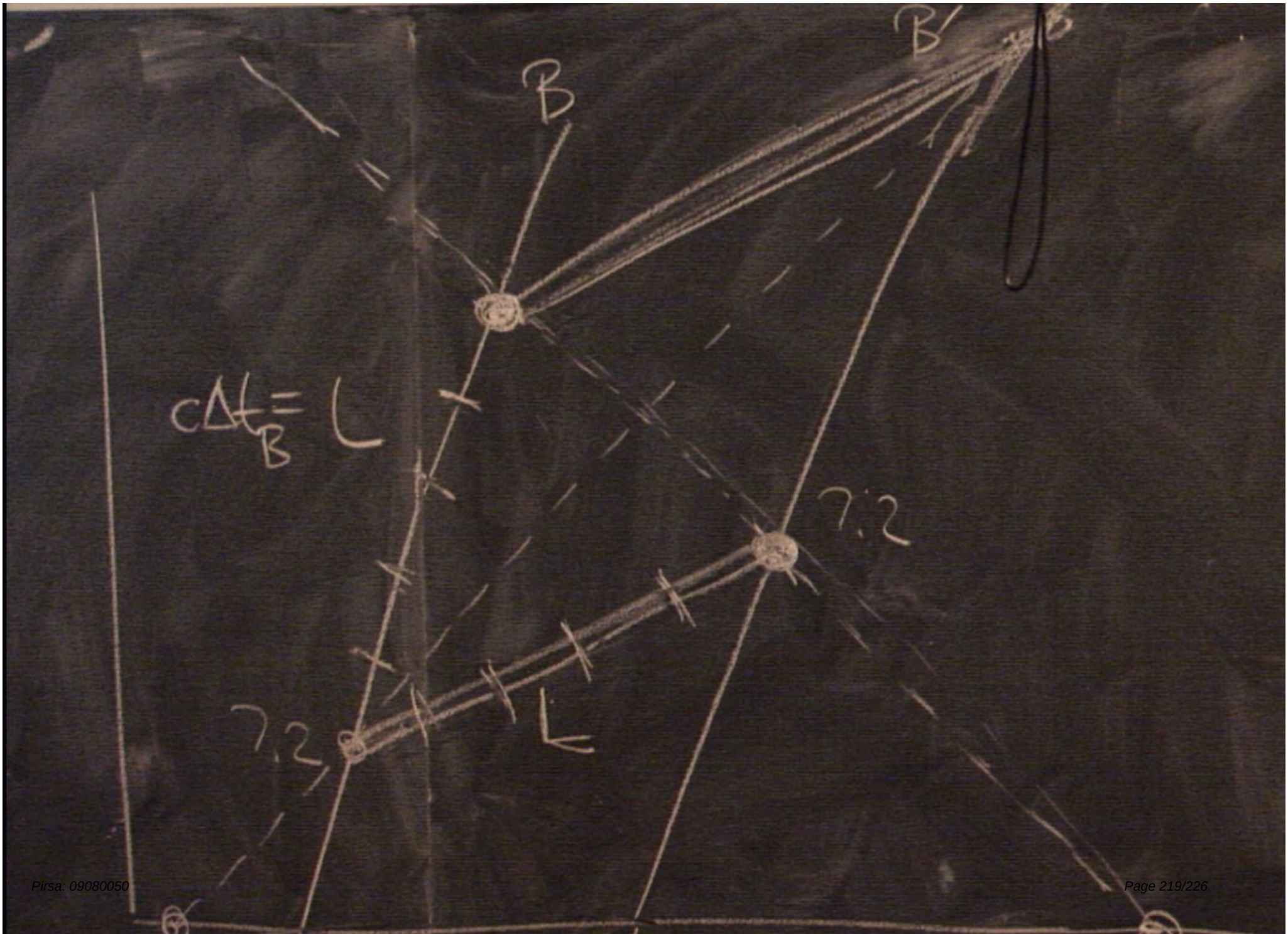

c/v
v/c
vel = dist / time
= L / v/c
= c
L
A
B
L

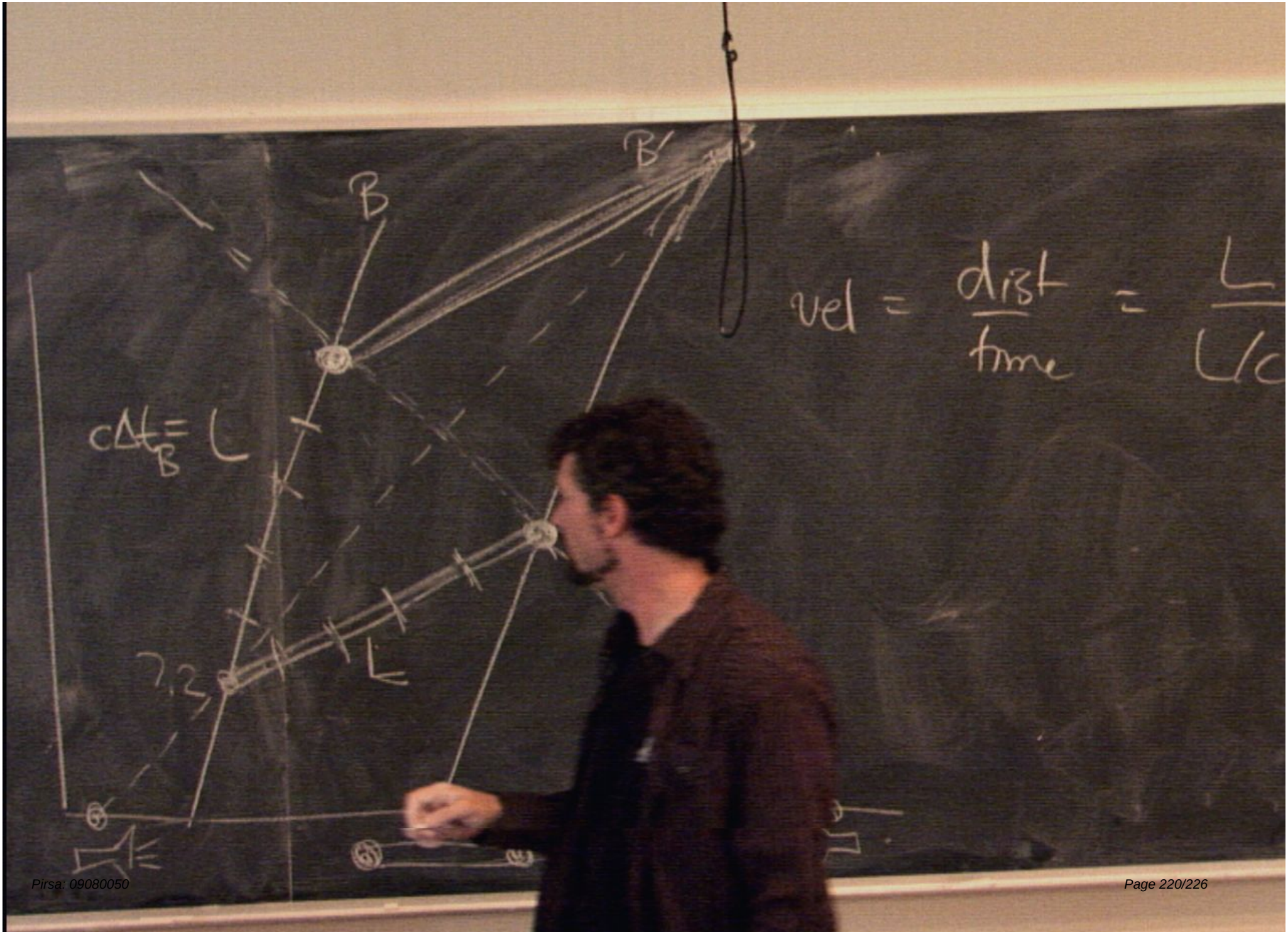

$c\Delta t_B = L$
L

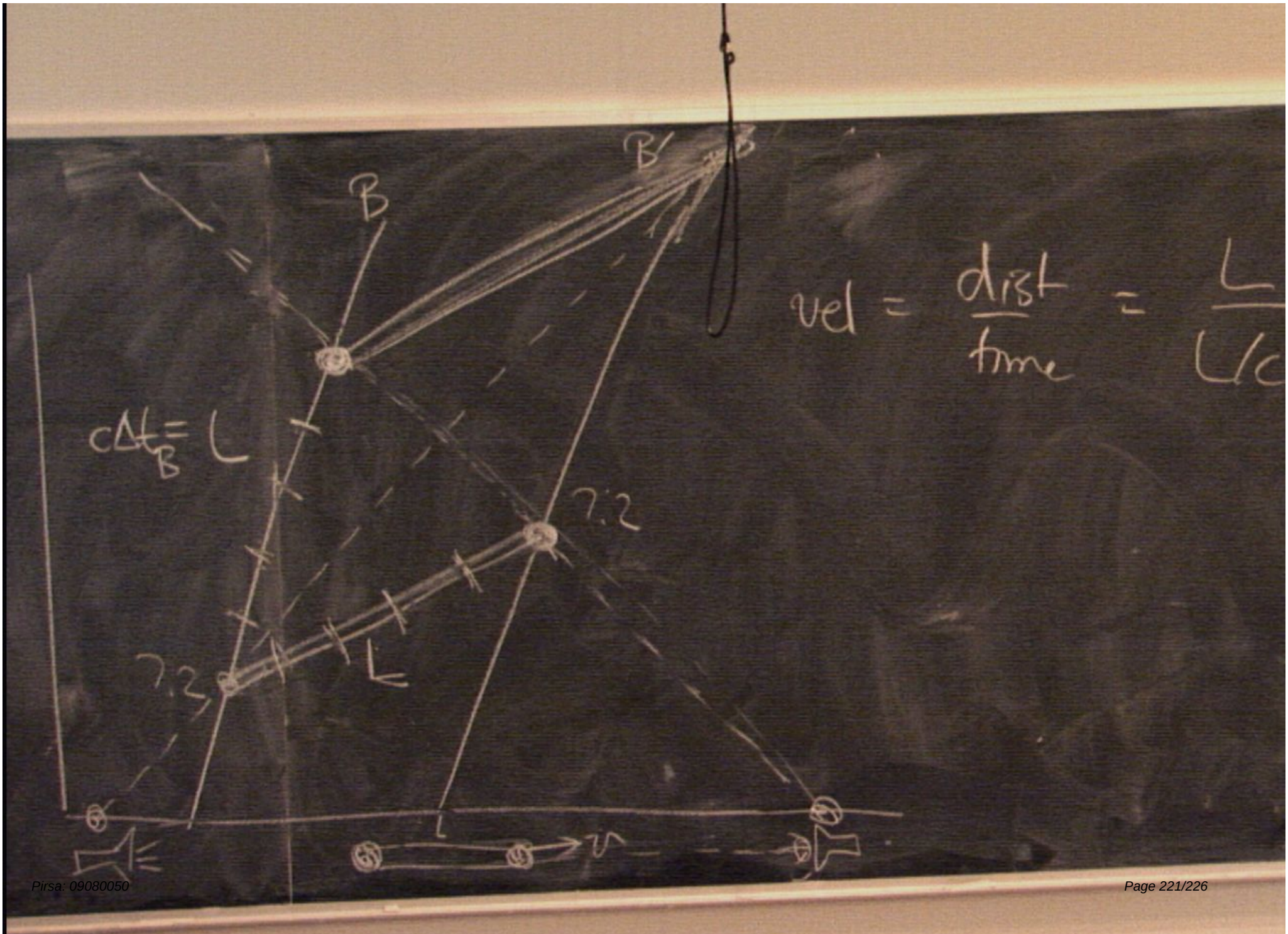

$c\Delta t_B = L$
L

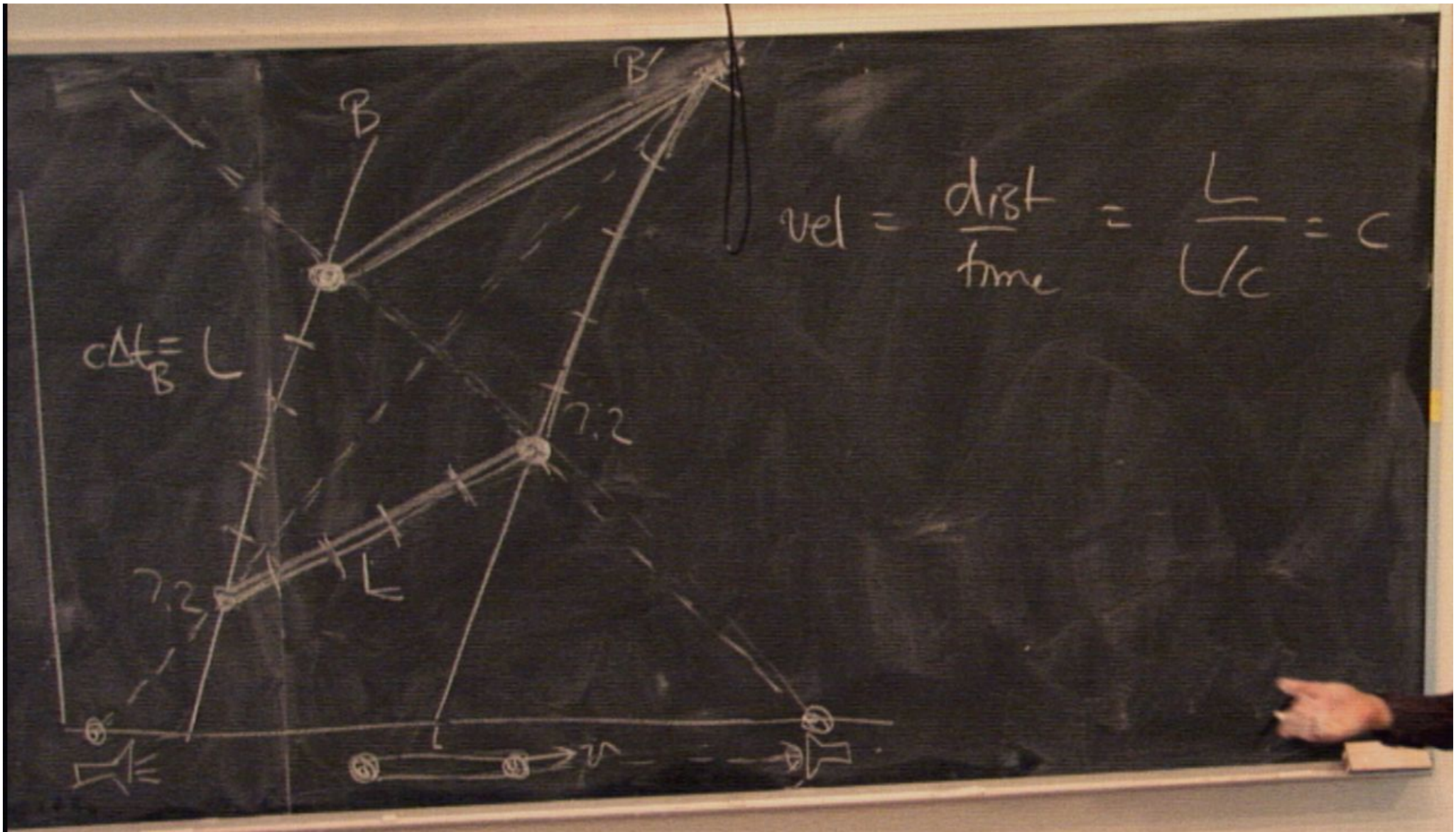

B
B'
$c\Delta t_B = L$
L

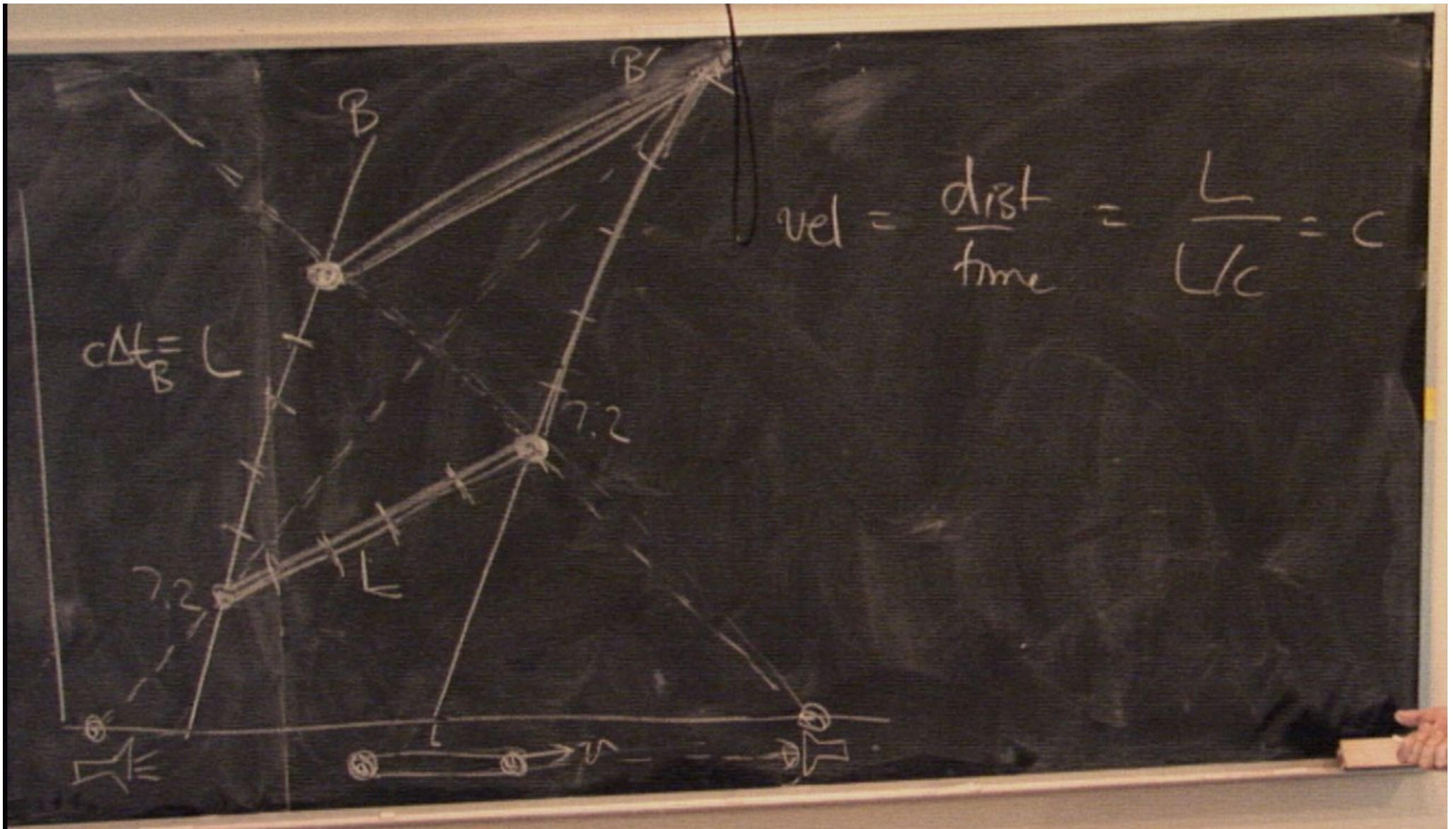

B
B'
$c\Delta t_B = L$
7:2
L

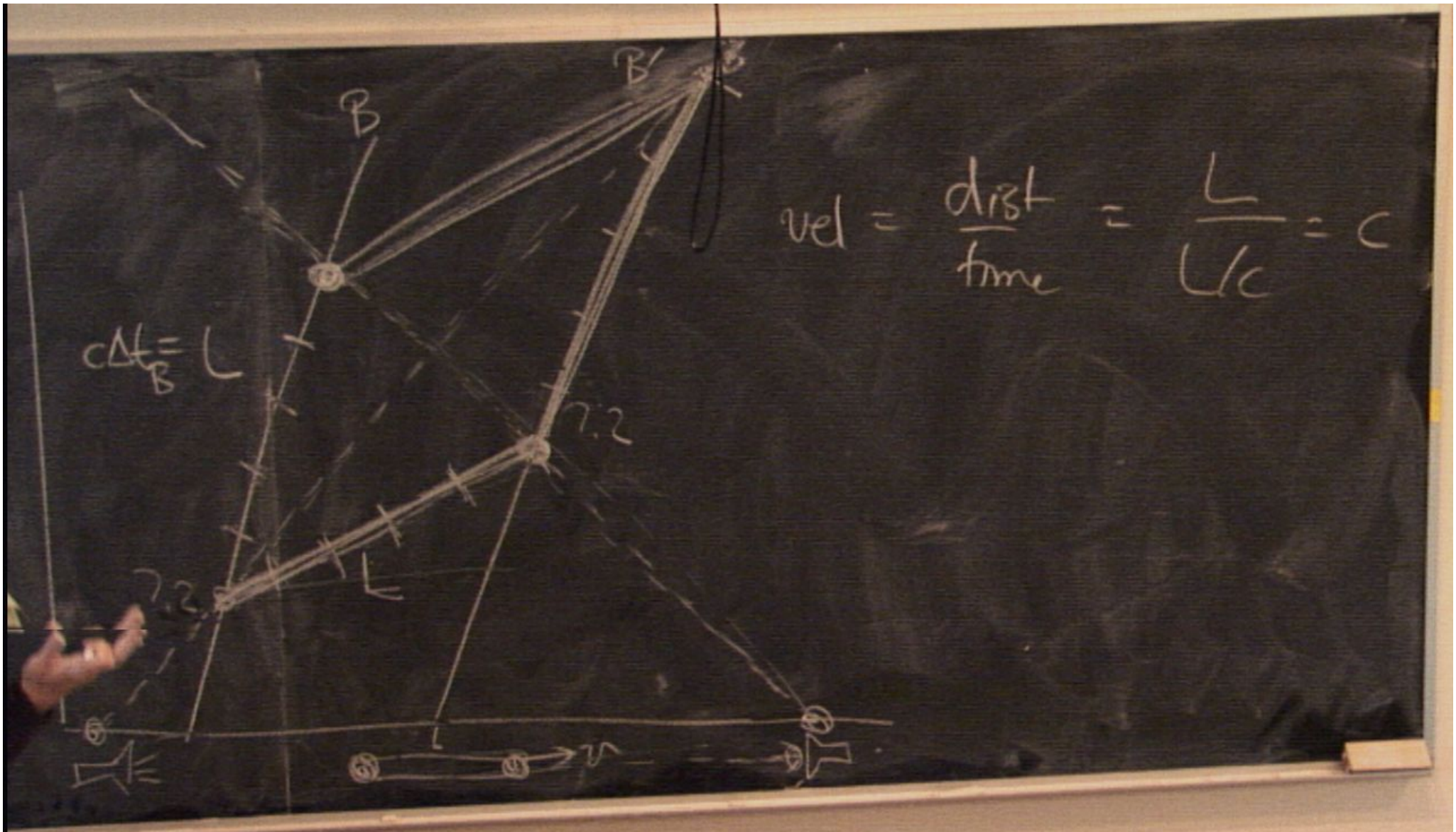

B
B'
$c\Delta t_B = L$
7:2
7:2
L

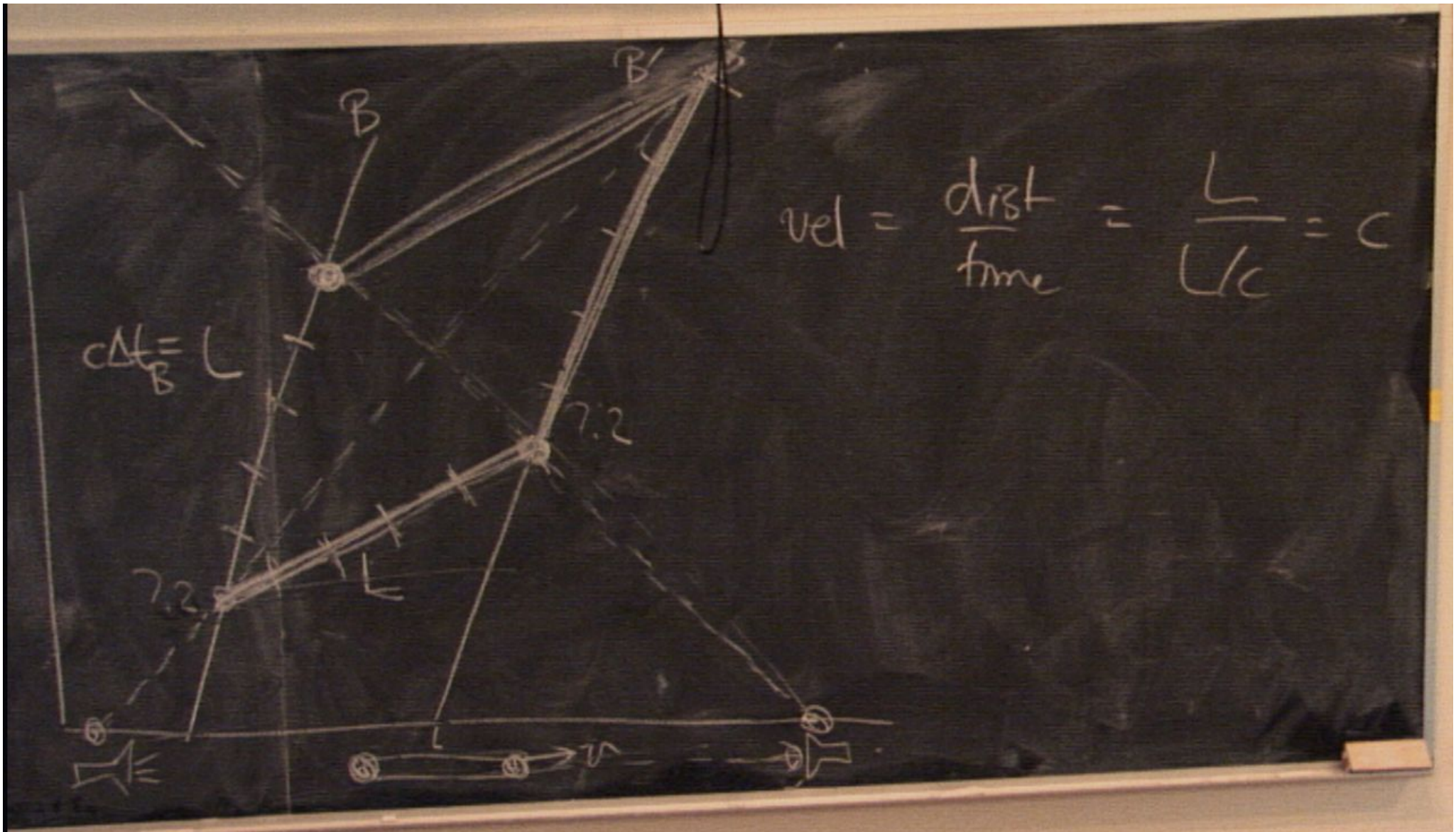

B
B'
vel = dist / time = L / L/c
cΔt_B = L
L

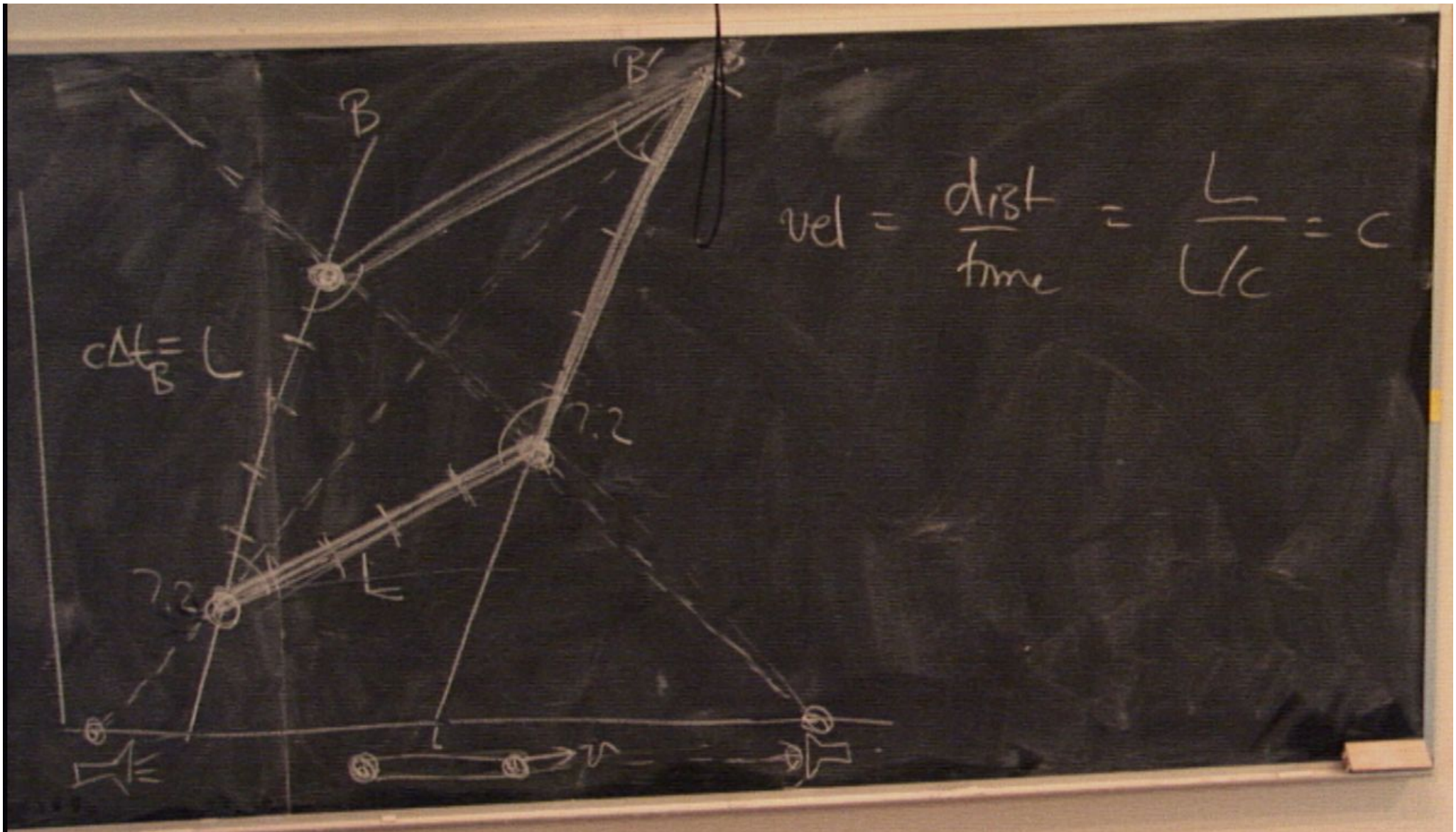

B'
B
B
vel = dist / time = L / L/c
cΔt_B = L
7:2
7:3
L
L
v


B
B'
$c\Delta t_B = L$
?.2
?.3
L
$vel = \frac{dist}{time} = \frac{L}{L/c} = c$


B
B'
$c\Delta t_B = L$
7.2
7.2
L
L
v
$vel = \frac{dist}{time} = \frac{L}{L/c} = c$


B
B'
B
$c\Delta t_B = L$
?.2
?.2
L
L
v
$vel = \frac{dist}{time} = \frac{L}{L/c} = c$


B
B'
B'
$c\Delta t_B = L$
?:2
?:2
L
L
v
$vel = \frac{dist}{time} = \frac{L}{L/c} = c$


B
B'
$c\Delta t_B = L$
7.2
7.2
L
v
$vel = \frac{dist}{time} = \frac{L}{L/c} = c$