

Title: Workshop on Ready-To-Use Teaching Resources on Modern Physics continued

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Abstract:

revolutionary explanation in the form of the *special theory of relativity*. He based it on two postulates.

Special Theory of Relativity

1. The relativity principle: all the laws of physics are valid in all inertial frames of reference.
2. The constancy of the speed of light: light travels through empty space with a speed of $c = 3.00 \times 10^8 \text{ m/s}$, relative to all inertial frames of reference.

relativity is an easy-to-accept extension of the idea of Newtonian relativity; merely Einstein proposed that not only Newtonian mechanics but all the laws of nature governing electricity, magnetism, and optics, are the same in all inertial frames. The second is more difficult to reconcile in our minds because it contradicts our common sense notions of relative motion. We would expect two observers, one on a train and the other moving away from it, to make two different measurements of the relative speed of light. According to Einstein, however, each would measure $c = 3.00 \times 10^8 \text{ m/s}$. Clearly, our everyday experiences and common sense help in dealing with motion at the speed of light.

Consistent with the notion of an absolute frame of reference, Einstein's theory solves Maxwell's equations: the speed of light predicted by Maxwell is not a speed relative to some frame of reference; it is the speed in *any* inertial frame of reference.

We recall that in Newtonian mechanics, while the laws of motion are the same in all frames, the appearance of any one particular motion is liable to change from frame to frame. We will see in the rest of this chapter that the position for Einstein is similar: the changes in the appearance of the world, as we move between inertial frames at high speeds with respect to each other, are contrary to common sense. Special relativity is a special case of the more general theory of relativity (not to be confused with the general theory of relativity), published by Einstein in 1916. The general theory of relativity extends the theory of special relativity to noninertial frames of reference.

The theory of special relativity and its many implications are now considered as a part of physics as Newton's laws. The difference is this: to comprehend the ramifications of the theories requires a great deal more mental flexibility and imagination than was the case with Newtonian mechanics.

Time Dilation

Let us now examine the consequences Einstein drew from his two postulates. In Newtonian mechanics, there is a universal time scale, the same for all frames. This seems right. Surely, a sequence of events that one observer measures would also last 2.0 s to an observer moving with respect to the first. But this is not always so! According to Einstein, time interval measurements depend on the reference frame in which they are made. The time interval between the occurrence of two or more events at the same time, is also a relative quantity. This makes it our starting point, before proceeding to the relativity of a time interval.

Let us do a thought experiment to show that events that are simultaneous in one frame are not simultaneous in other frames.

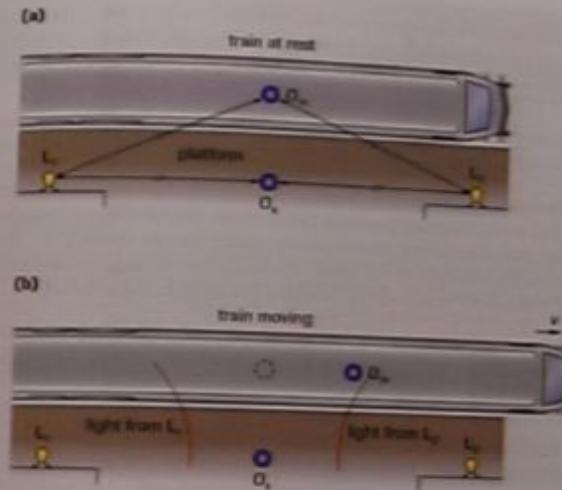


Figure 5

(a) When the train is at rest, each observer sees the lamps flash simultaneously, since each observer is halfway between the lamps.

(b) When the train is moving, each observer does not see the lamps flash simultaneously, since the light from L_1 takes longer to reach O_1 than the light from L_2 , that is, $\Delta t_{L_1} > \Delta t_{L_2}$.

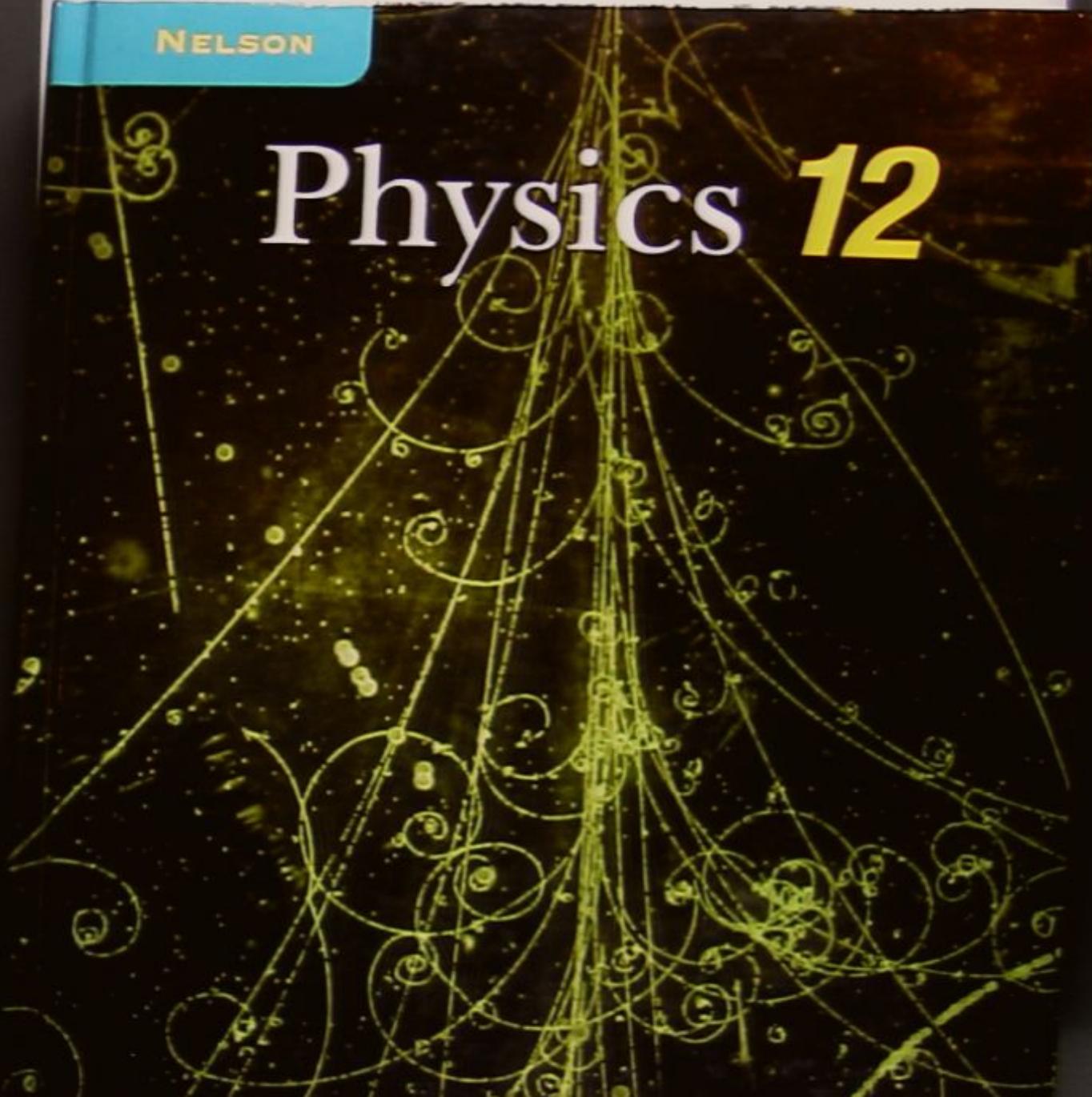
In Figure 5(a), the train is at rest relative to Earth. The train has two lamps, L_1 and L_2 , connected to a single electrical circuit. A switch on the train controls both lamps. The train is positioned on a straight track next to a railway platform. Two observers, O_1 and O_2 , are on the platform. O_1 is located at the midpoint between the two lamp posts, L_1 and L_2 . O_2 is located at the midpoint between O_1 and L_2 . The train is at rest relative to the platform. The lamps are turned on simultaneously. The light from both lamps travels in straight lines towards the observers. Since the train is at rest, the distance from each lamp to each observer is the same. Therefore, the light from both lamps reaches both observers simultaneously.

In Figure 5(b), the train is moving to the right with a constant velocity v relative to Earth. The train is positioned on a straight track next to a railway platform. Two observers, O_1 and O_2 , are on the platform. O_1 is located at the midpoint between the two lamp posts, L_1 and L_2 . O_2 is located at the midpoint between O_1 and L_2 . The train is moving to the right with a constant velocity v relative to the platform. The lamps are turned on simultaneously. The light from both lamps travels in straight lines towards the observers. However, the distance from L_1 to O_1 is greater than the distance from L_2 to O_1 . Therefore, the light from L_1 reaches O_1 before the light from L_2 . The distance from L_2 to O_2 is greater than the distance from L_1 to O_2 . Therefore, the light from L_2 reaches O_2 before the light from L_1 .

We now perform the second trial in the thought experiment, letting the train move by O_1 at a high speed relative to the inertial frame of Earth but keeping everything else as before. In the time interval it takes for the flash of light to travel to O_1 from each lamp post, O_1 will have moved a short distance to the right (Figure 5(b)). In this time interval O_2 will receive the flash of light from L_2 but not yet receive the flash of light from L_1 . O_1 thus sees the rear lamp flash a little later than the forward lamp. Having taken this observation, O_1 now performs measurements, as in the first trial: he is halfway between the soot marks left on the train, and light always travels at the same speed, c . Therefore, O_1 is forced to conclude that the two lamps did not flash simultaneously. We emphasize that the conclusion of nonsimultaneity relies on Einstein's second postulate. Since (as the placement of the soot marks reveals) the distances are equal, and since the light flashes travelled at the

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Physics 12



the special theory of relativity. His

physics are valid

light travels
 $c = 3.00 \times 10^8 \text{ m/s}$,
etc.

idea of Newtonian relativity, classical mechanics but *all* the laws of motion, and optics, are the same in all frames of reference in our minds because it contradicts what we would expect two observers, one moving relative to the other, to make two different measurements. To Einstein, however, each would have different everyday experiences and common sense would be violated.

In reference, Einstein's theory solves the problem of how light can travel faster than the speed of light in an inertial frame of reference.

The laws of motion are the same in all frames of reference. The law of inertia is liable to change from frame to frame. The law of gravitation for Einstein is similar to that of Newton in the world as we move between inertial frames. The laws of optics are contrary to common sense. The theory of relativity is not consistent with the general theory of relativity (not yet). The general theory of relativity is not consistent with the theory of quantum mechanics.

Many implications are now considered. The theory of relativity is now considered to be more difficult to comprehend than the theory of quantum mechanics. The theory of relativity is now considered to be more difficult to comprehend than the theory of quantum mechanics.

Einstein drew from his two postulates that time is a universal time scale, the same for all events that one observer measures, and that time interval measurements are the same for all observers.

Time, at the same time, is also a relative concept according to the relativity of a time interval between events that are simultaneous in different frames of reference.

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Section 11.1

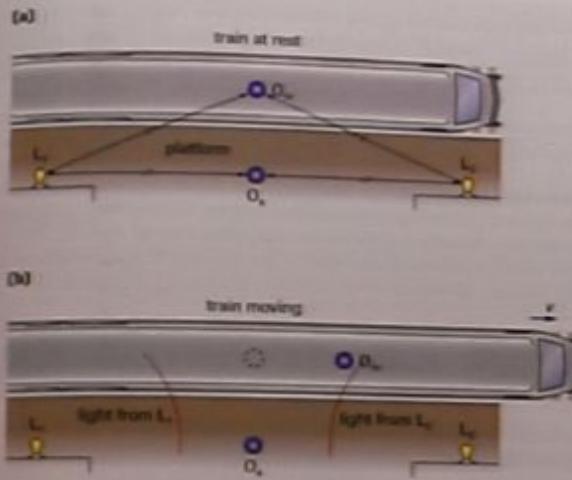


Figure 5

(a) When the train is at rest, each observer sees the lamps flash simultaneously, since each observer is halfway between the lamps.

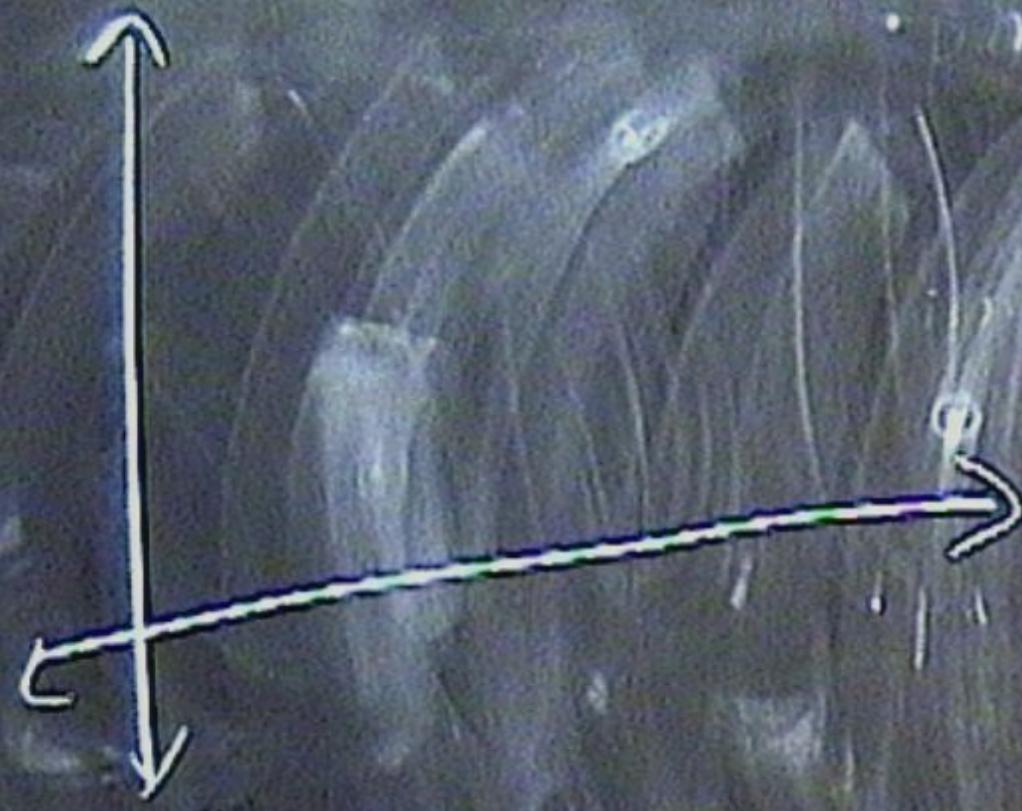
(b) When the train is moving, each observer does not see the lamps flash simultaneously, since the light from L₁ takes longer to reach O₁ than the light from L₂, that is,

$$\Delta t_1 > \Delta t_2$$

inertial frame anchored in the railway platform, the lamps come on at the same time when the switch is closed. To make the experiment easy to follow, we assume that the lamps do not stay on when the current is applied but flash and explode, spewing out soot and broken glass. The light from each flash travels out in all directions at the speed of light, c . Since O₁ is located at the midpoint between the lampposts, the distances the beams of light travel are equal, causing the arrival of light from the one lamp to be simultaneous with the arrival of light from the other lamp. Adjacent to O₁ is a second observer O₂, sitting in a train on a straight track next to the platform. We make two trials in our thought experiment: in the first, keeping the train at rest relative to Earth, and in the second, making the train move with speed v relative to Earth.

If the train is at rest, O₁ finds the arrival of the light from the first lamp to be simultaneous with the arrival of the light from the second lamp (Figure 5(a)). O₁ then performs measurements of the soot marks left by the exploding lamps on his train: he is halfway between the soot marks, and light always travels at the same speed, c . Therefore, O₁ is forced to conclude that the lamps flashed simultaneously. O₂ reaches the same conclusion for the same reasons.

We now perform the second trial in the thought experiment, letting the train move by O₁ at a high speed relative to the inertial frame of Earth but keeping everything else as before. In the time interval it takes for the flash of light to travel to O₁ from each lamppost, O₁ will have moved a short distance to the right (Figure 5(b)). In this time interval O₁ will receive the flash of light from L₂ but not yet receive the flash of light from L₁. O₁ thus sees the rear lamp flash a little later than the forward lamp. Having taken this observation, O₁ now performs measurements, as in the first trial: he is halfway between the soot marks left on the train, and light always travels at the same speed, c . Therefore, O₁ is forced to conclude that the two lamps did not flash simultaneously. We emphasize that the conclusion of non-simultaneity relies on Einstein's second postulate. Since (as the placement of the soot marks reveals) the distances are equal, and since the light flashes travelled at the



Platform

ct



Platform

$$A = LI$$

x

$c\tau$



Platform

A = Light
B = "

X turned on
2



Platform 5 seconds

A = Light
B = "

X turned on
2



Platform
5 seconds

A = Light

B = "

$\frac{x}{T}$ turned on, $x=1m$
" " , $x=10m$

ct



Platform

both 5 seconds

A = Light

B = "

$\frac{x}{2}$

x turned on, $x = 1\text{m}$
" " , $x = 10\text{m}$



Platform
both 5 seconds

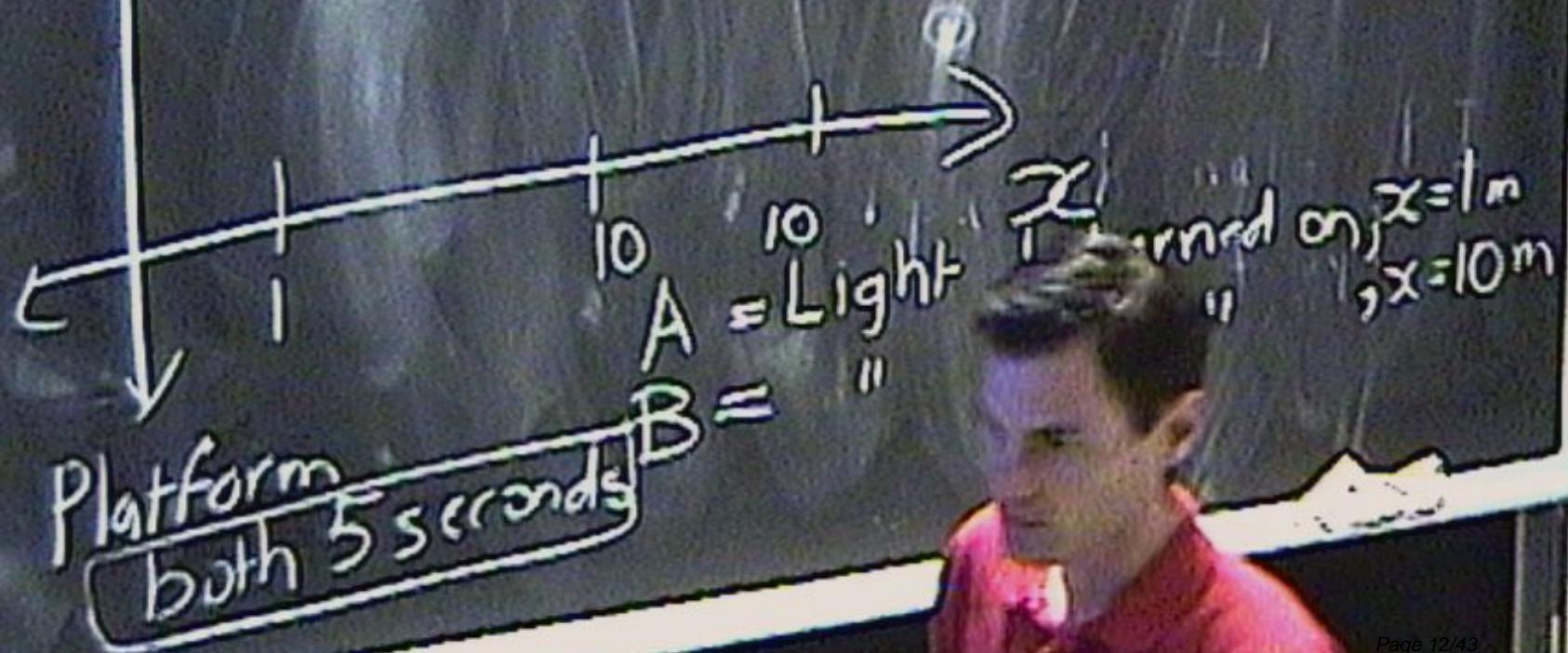
A = Light

B = "

$\frac{1}{2}$

x turned on, $x = 1m$
 $"$, $x = 10m$

ct



ct



A'

B

10

A =

2

X

turned on, $x=1m$
", $x=10m$

Platform
both 5 seconds

$c t$

A'

B

$c t$

Platform
both 5 seconds

10

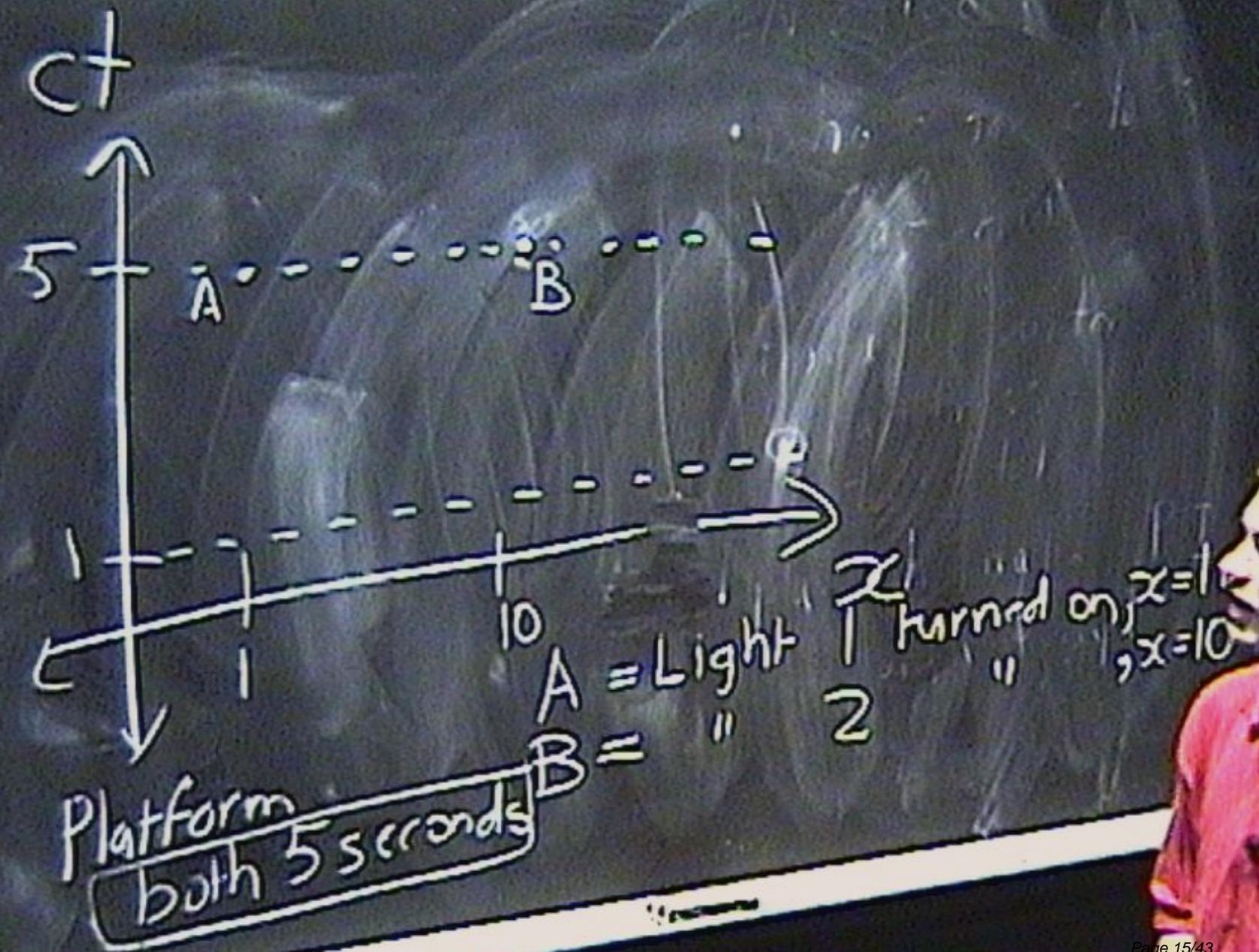
B =

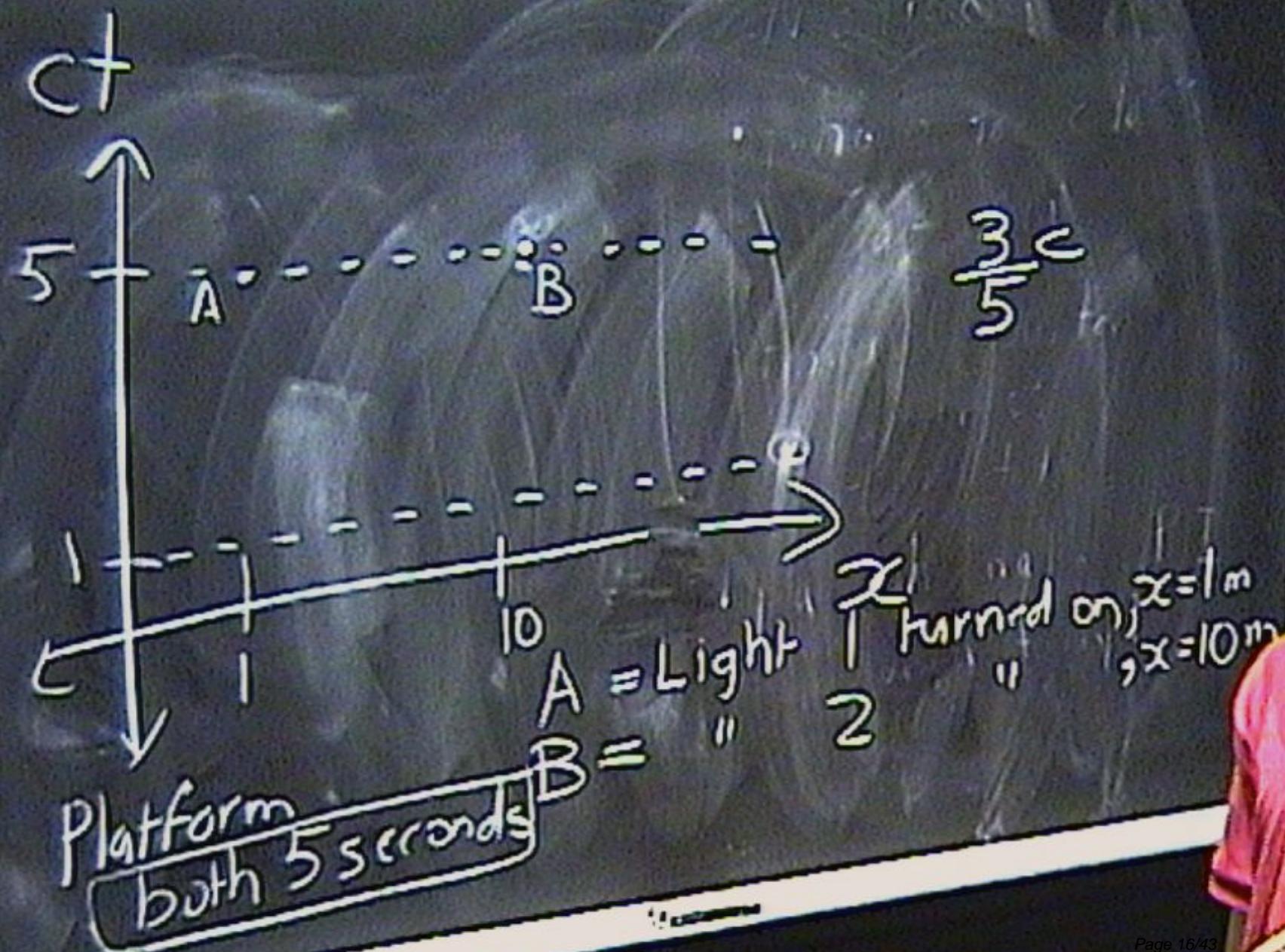
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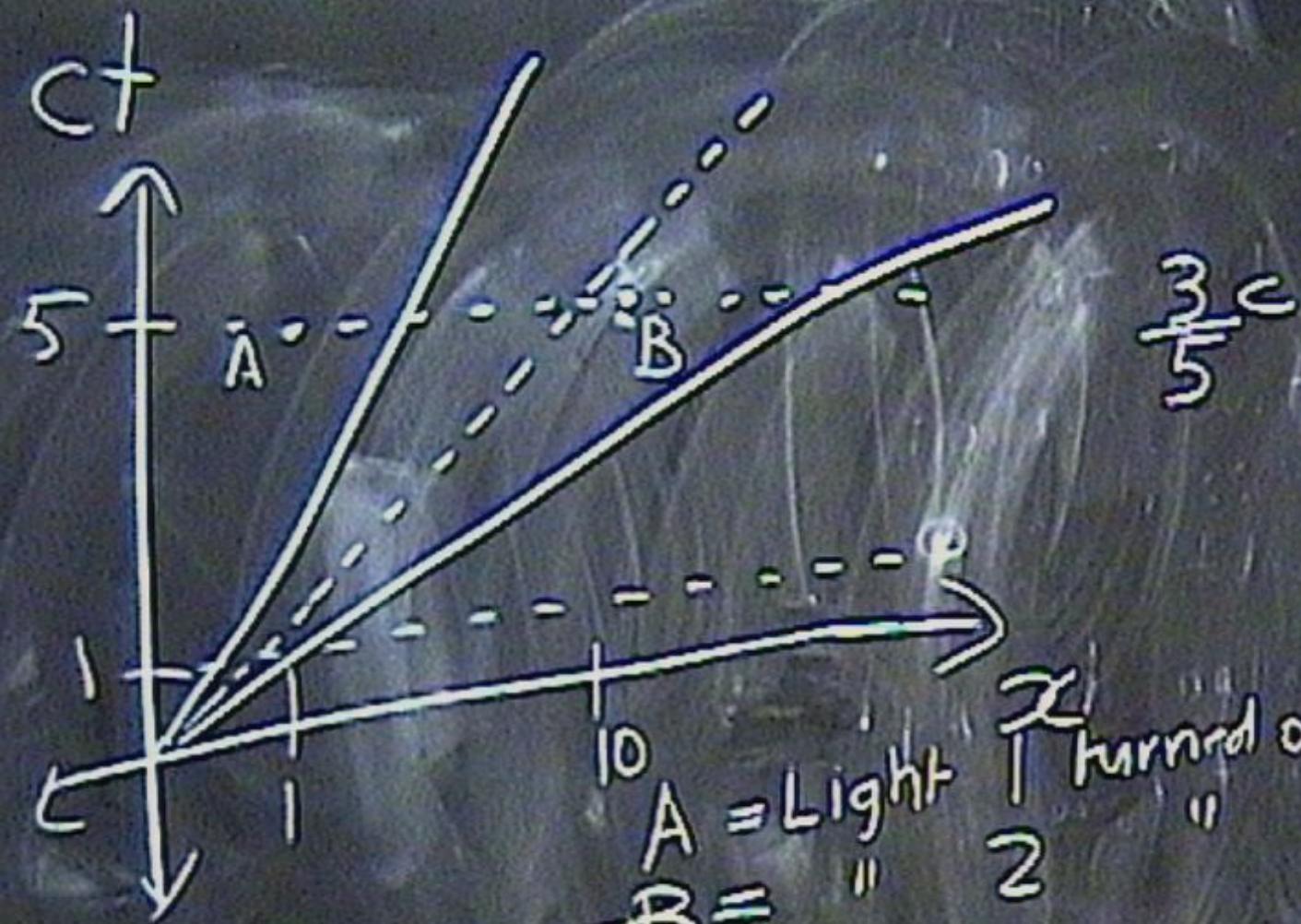
2

X turned on
" "









Platform
both 5 seconds

A

B

= Light

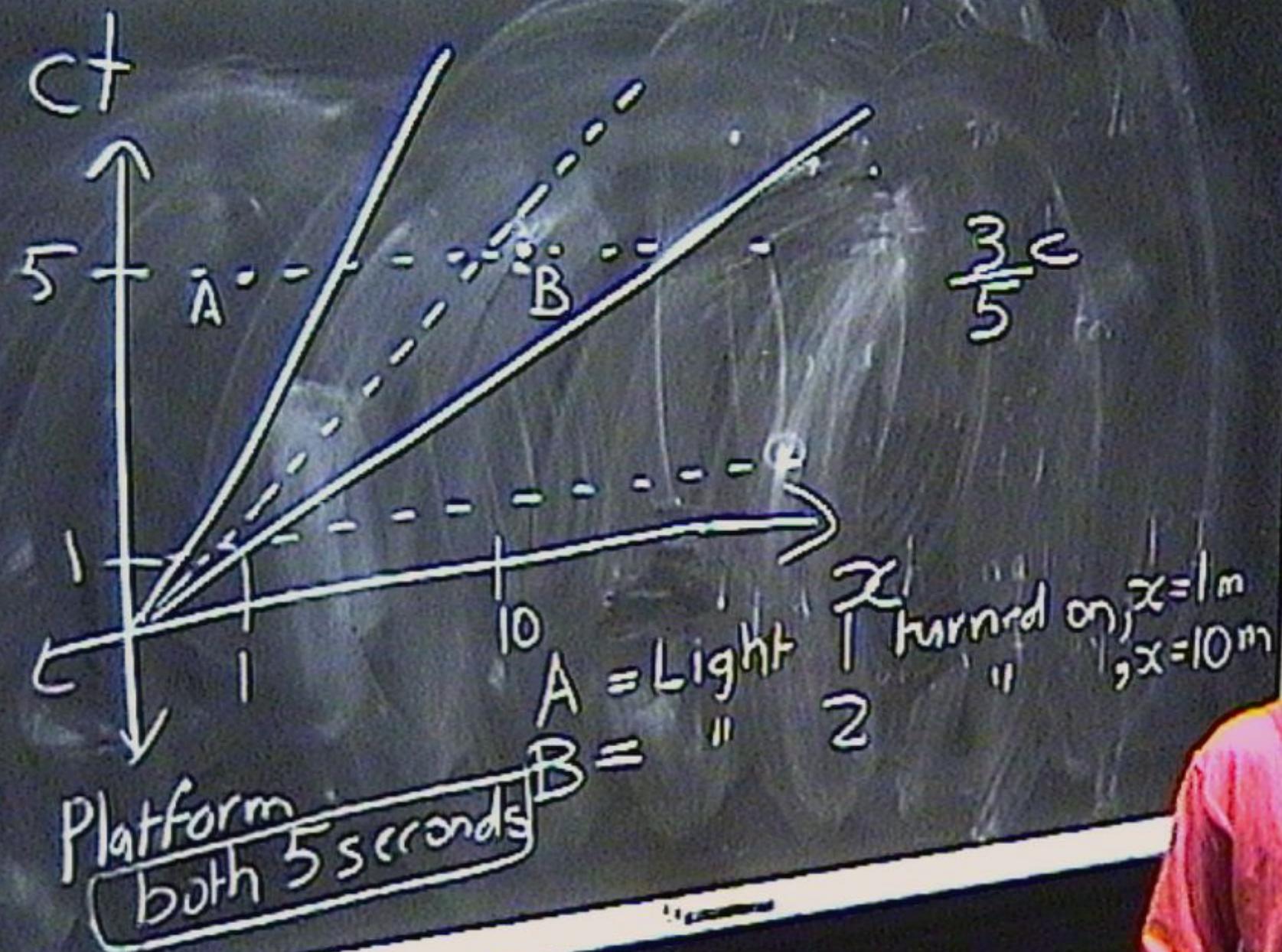
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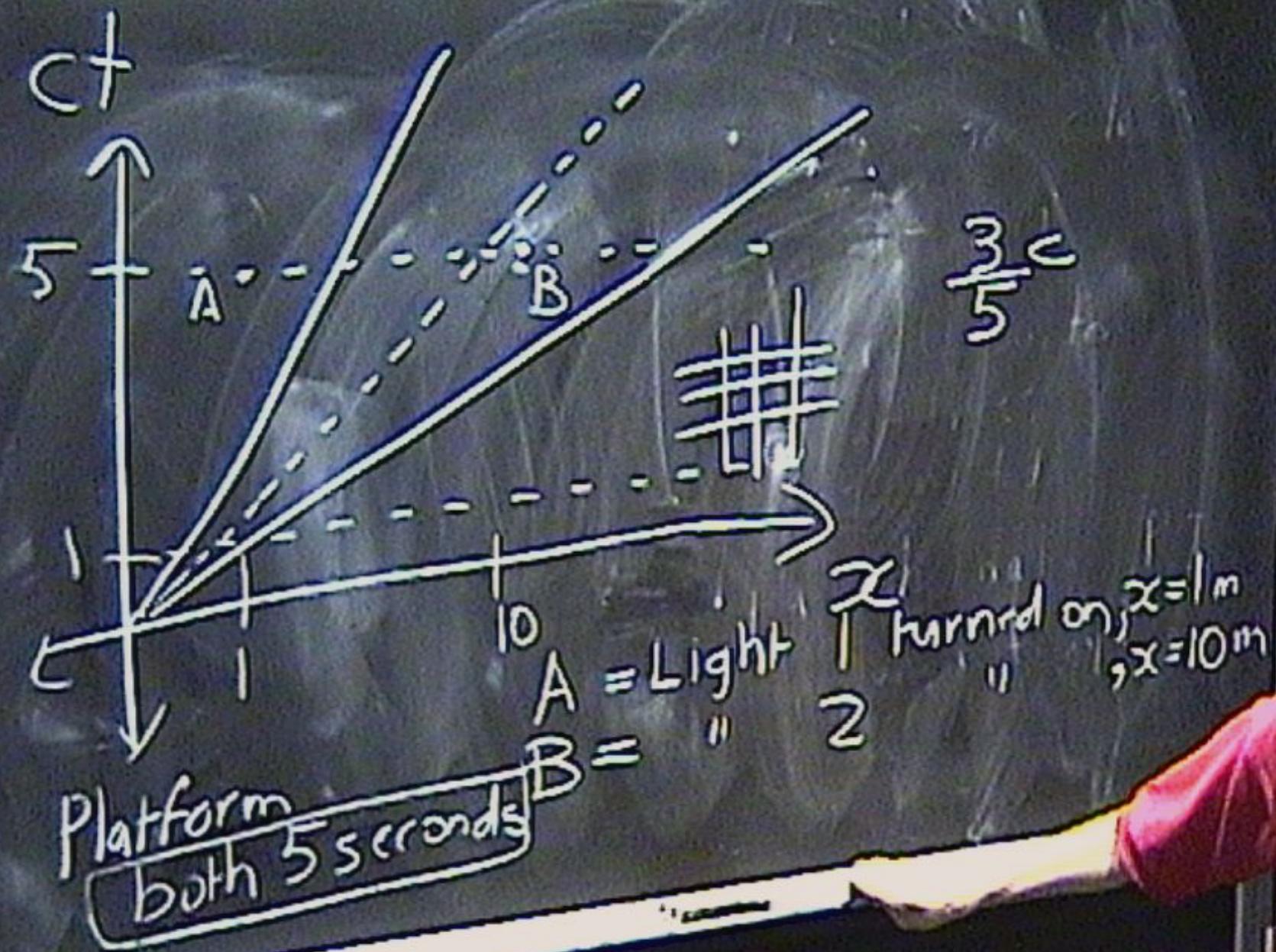
2

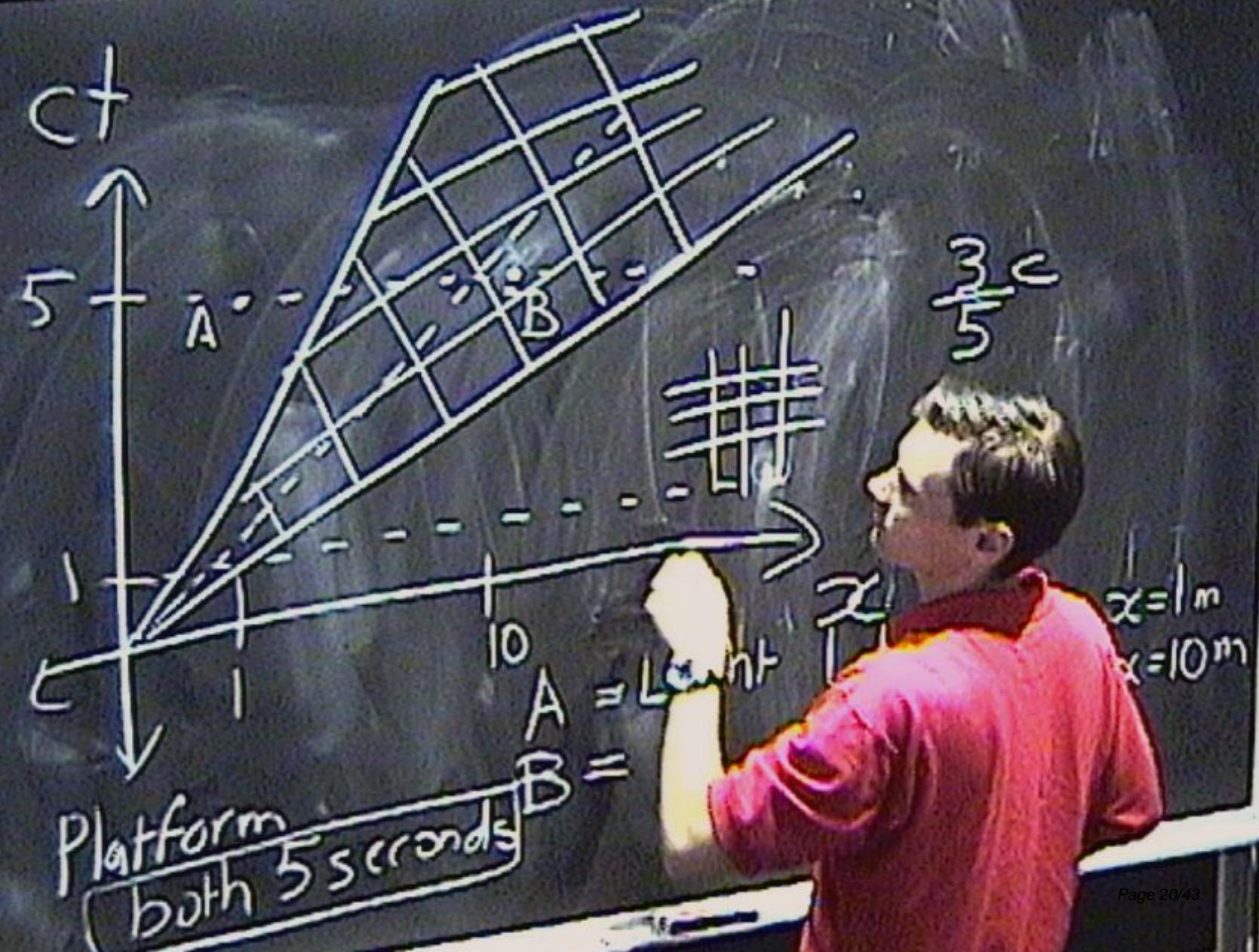
X

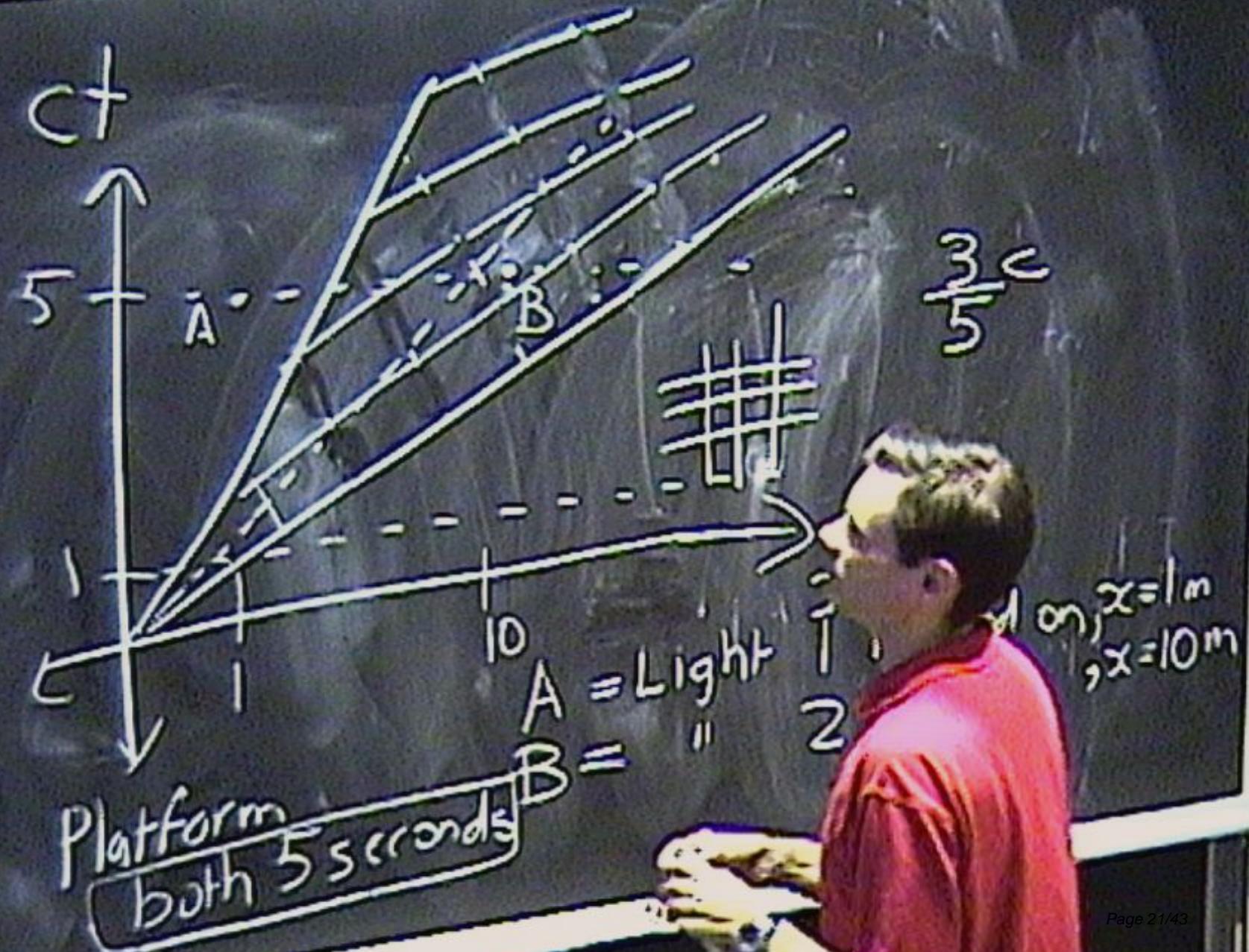
1

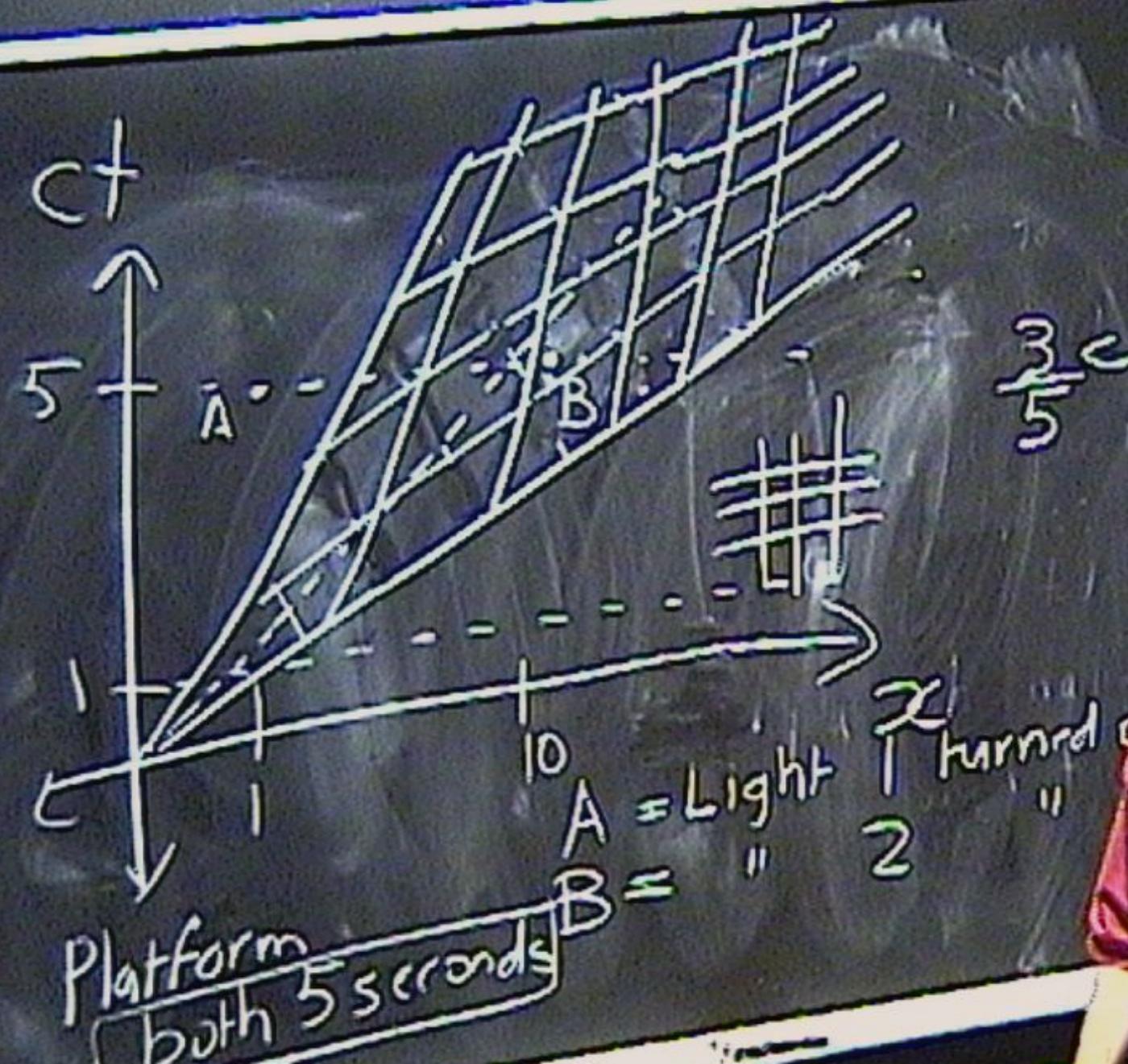
turn red on, $x=1m$
" " , $x=10m$

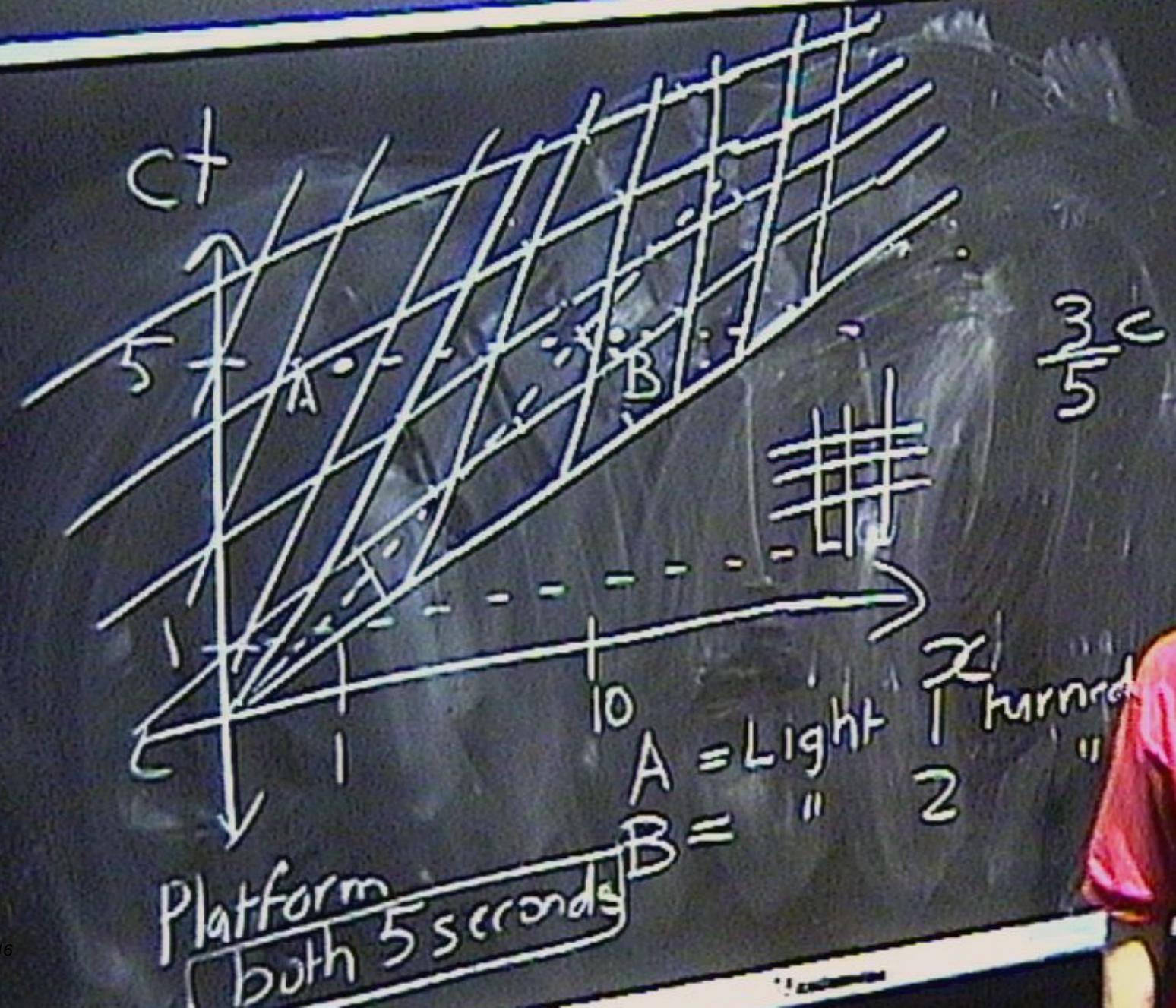


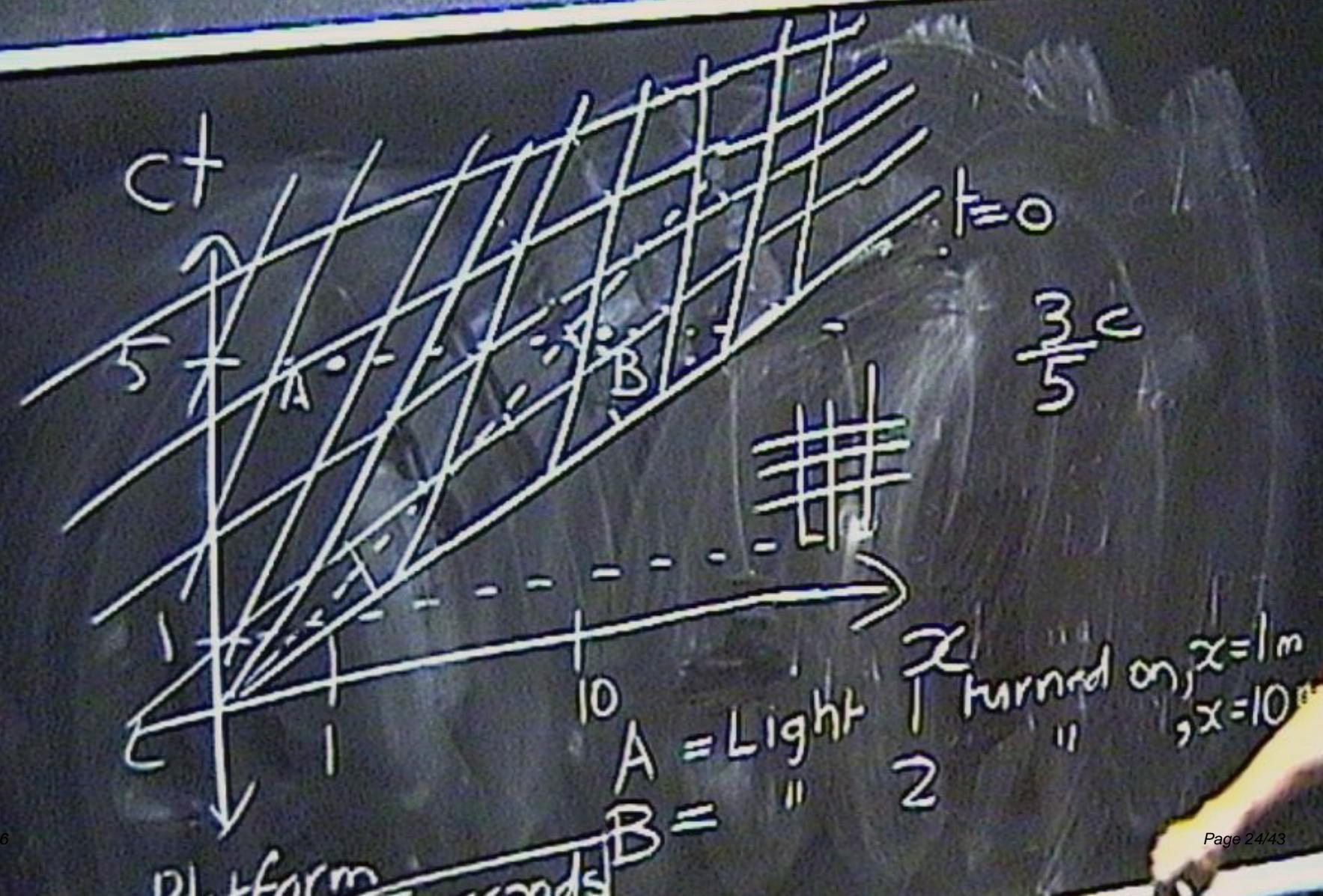


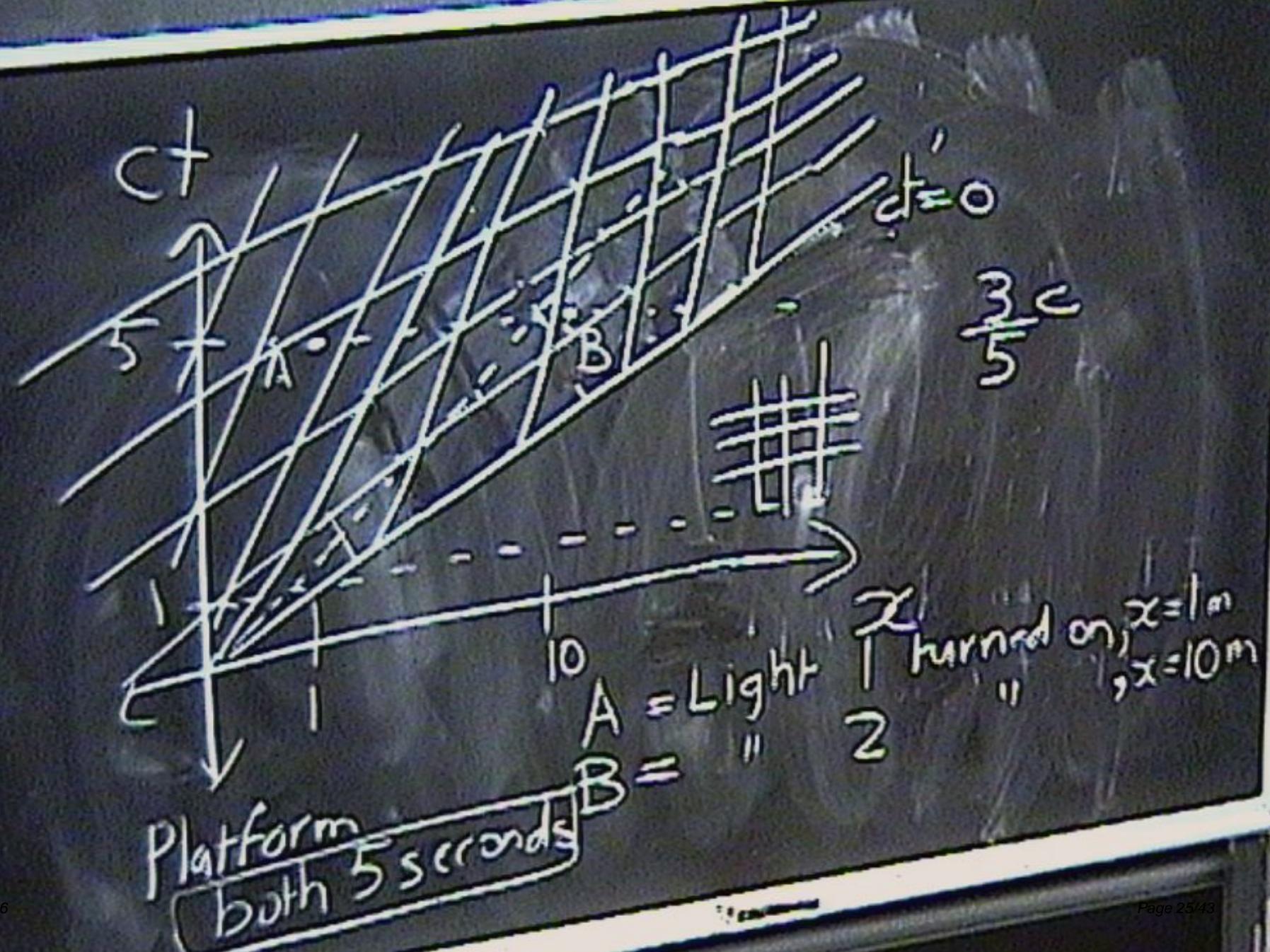


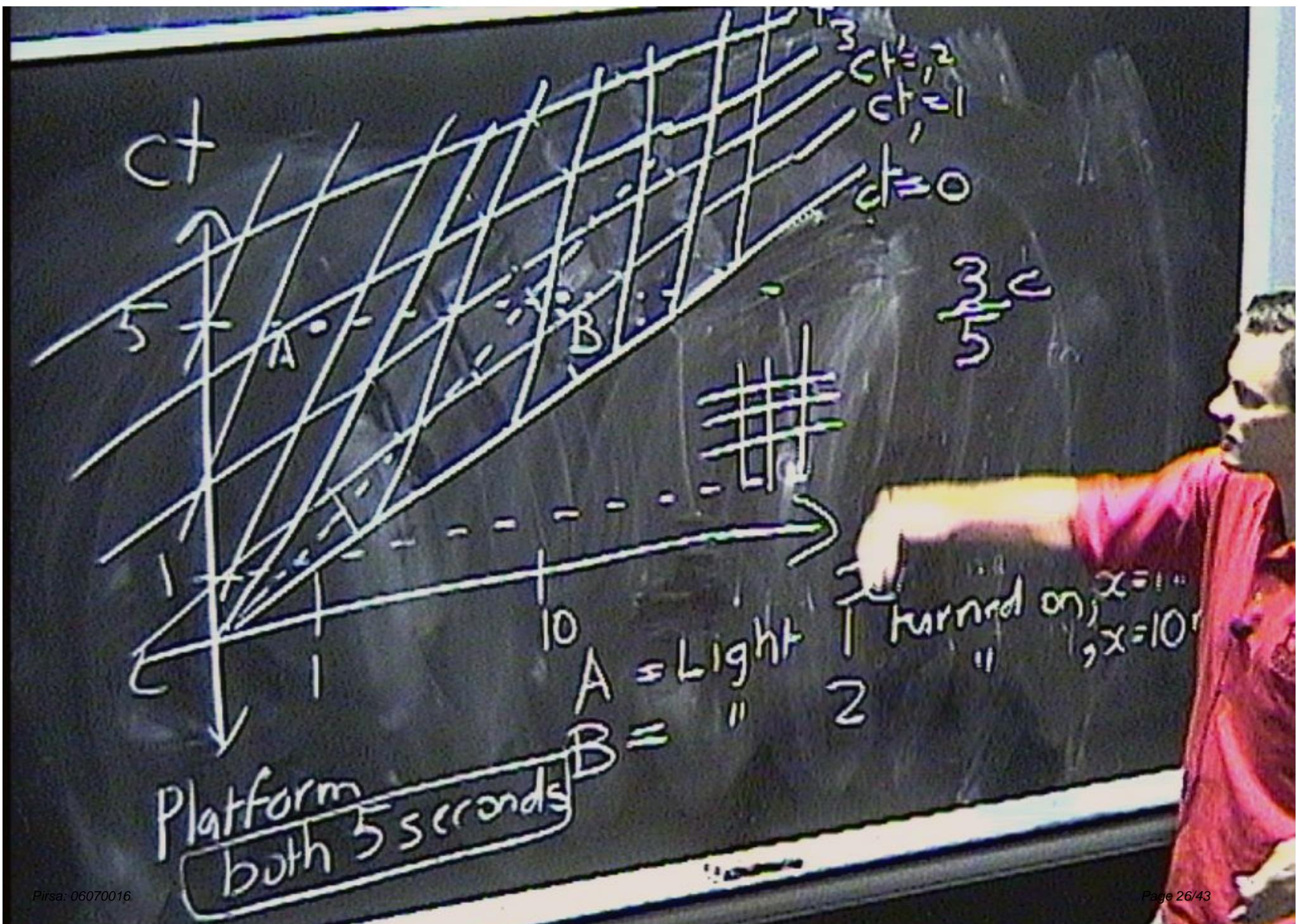


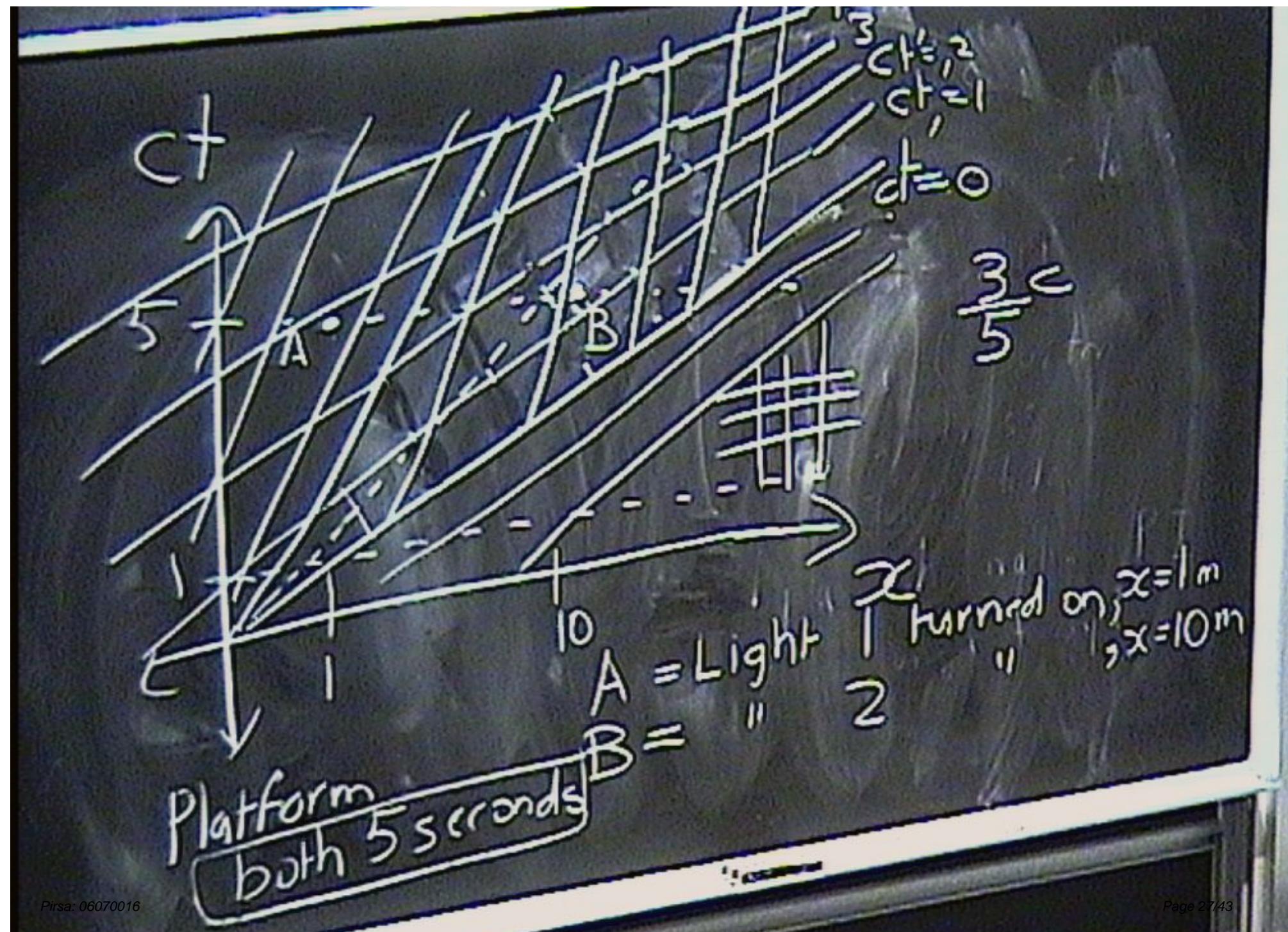


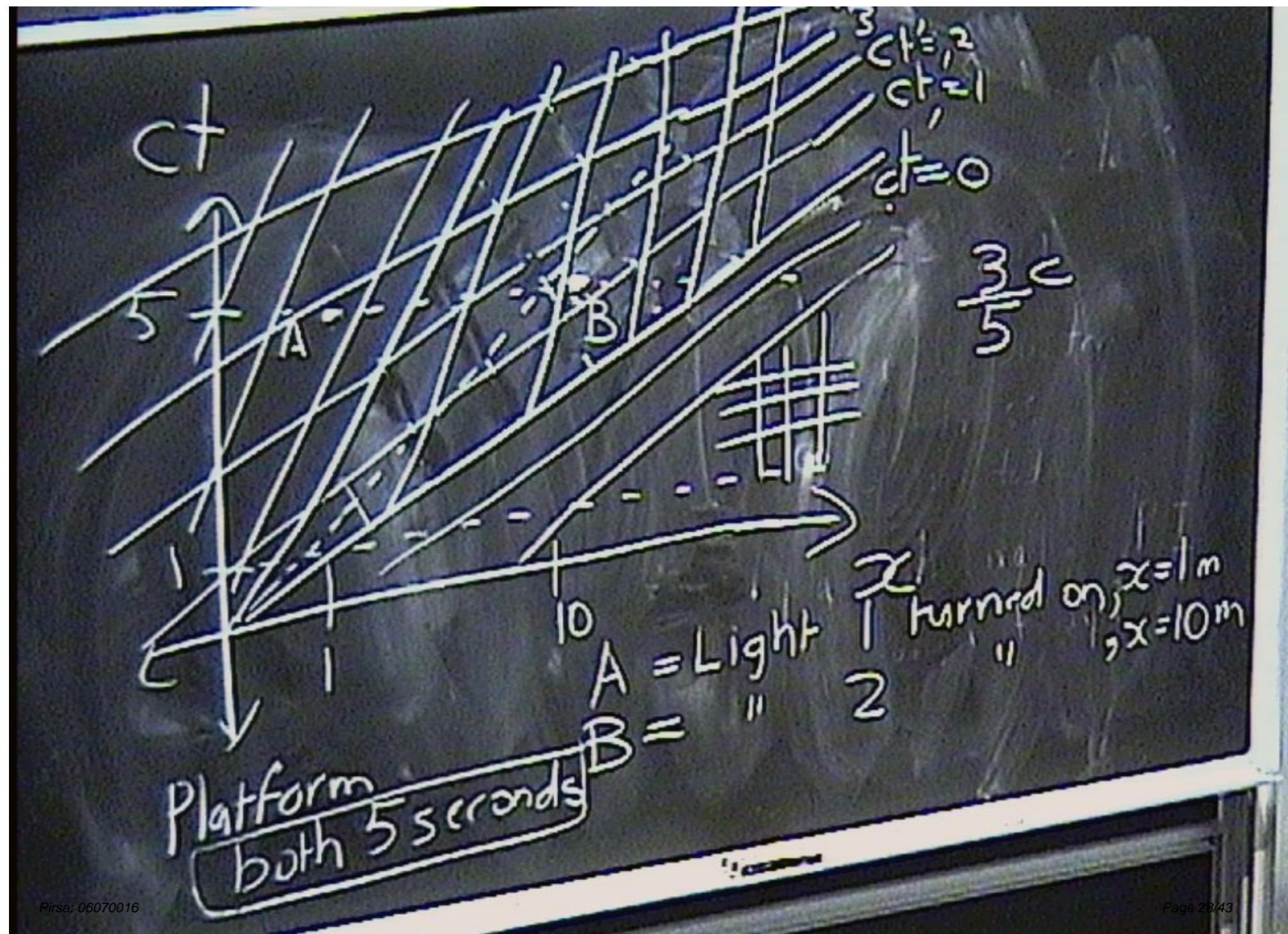


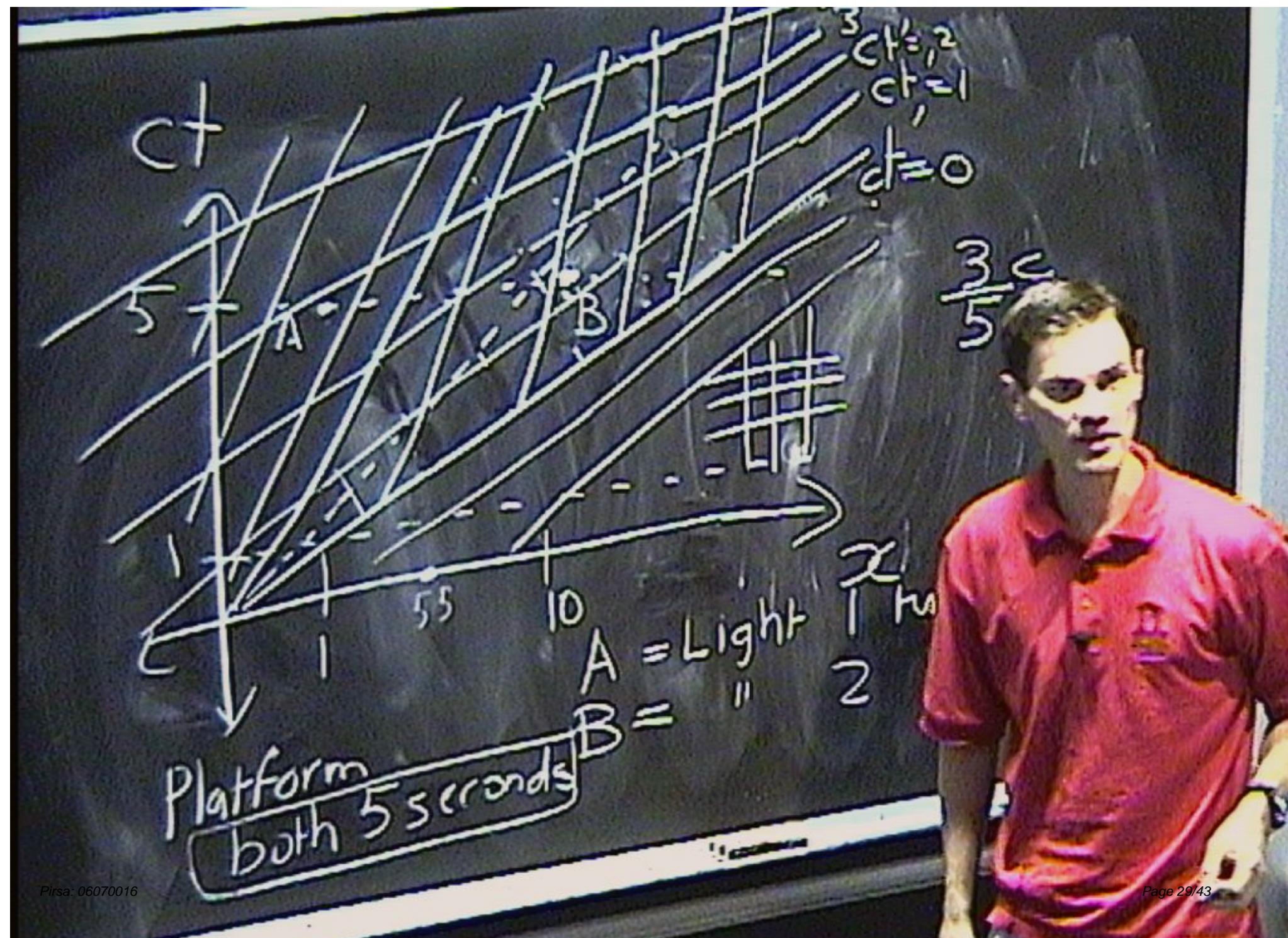


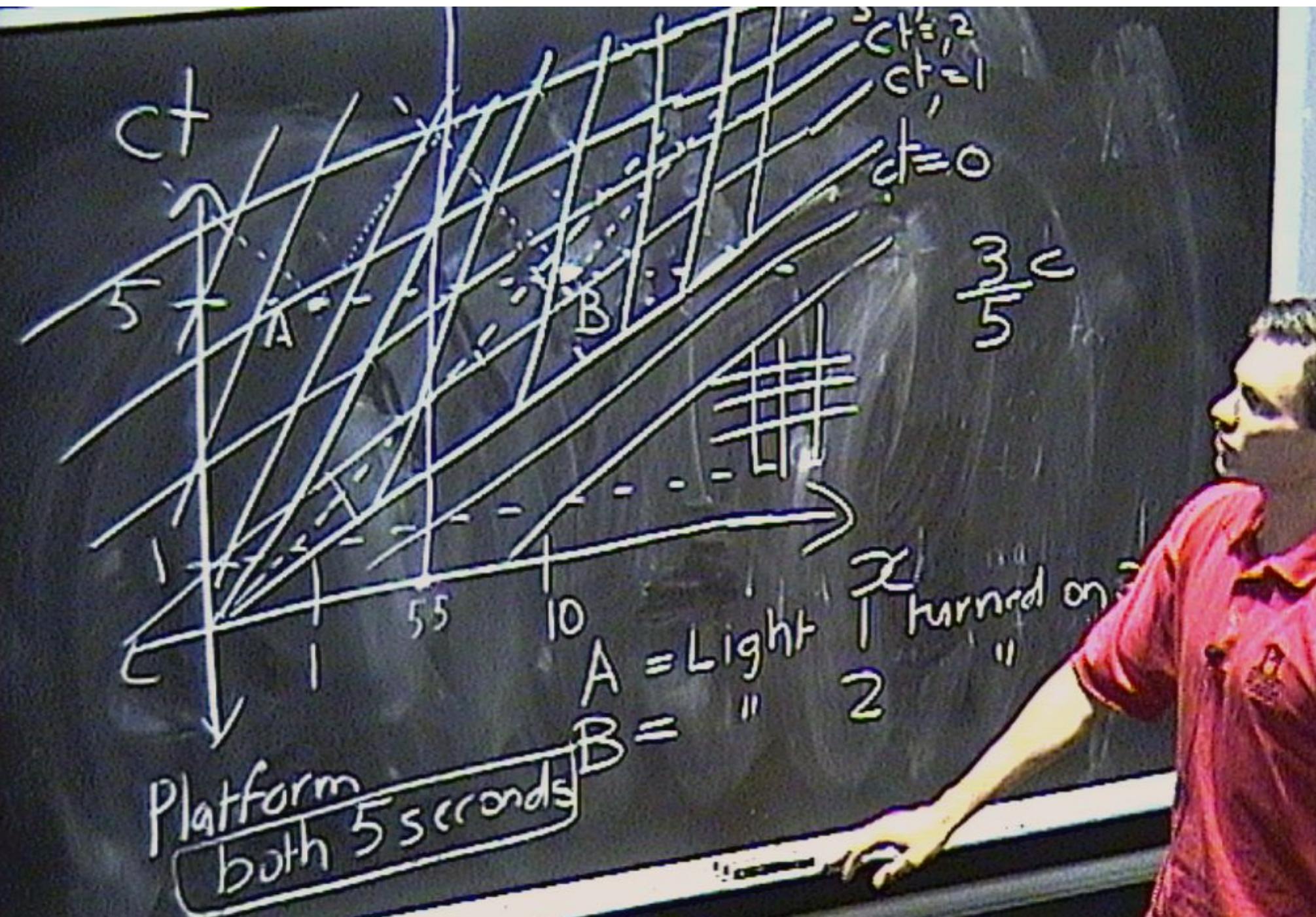


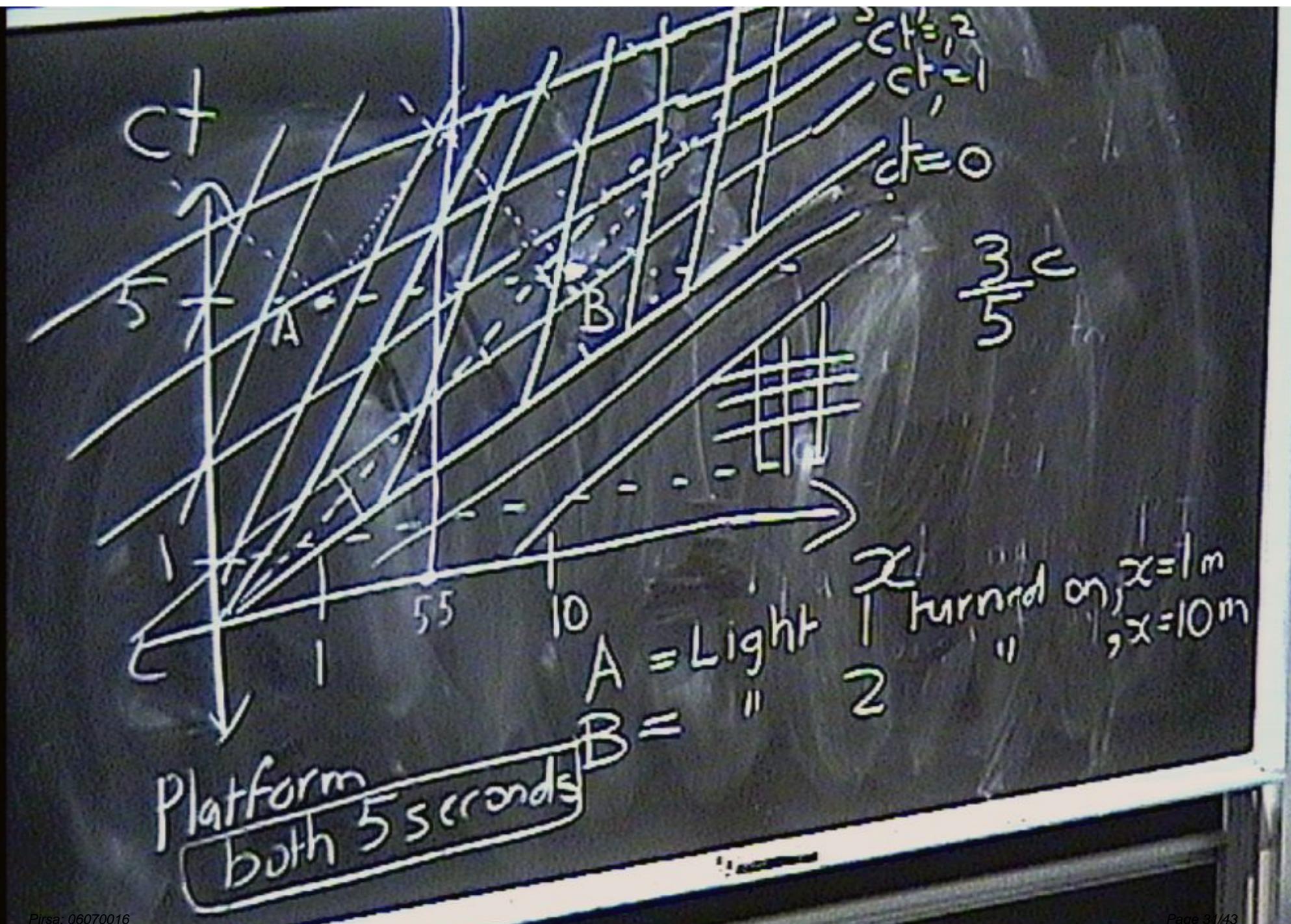


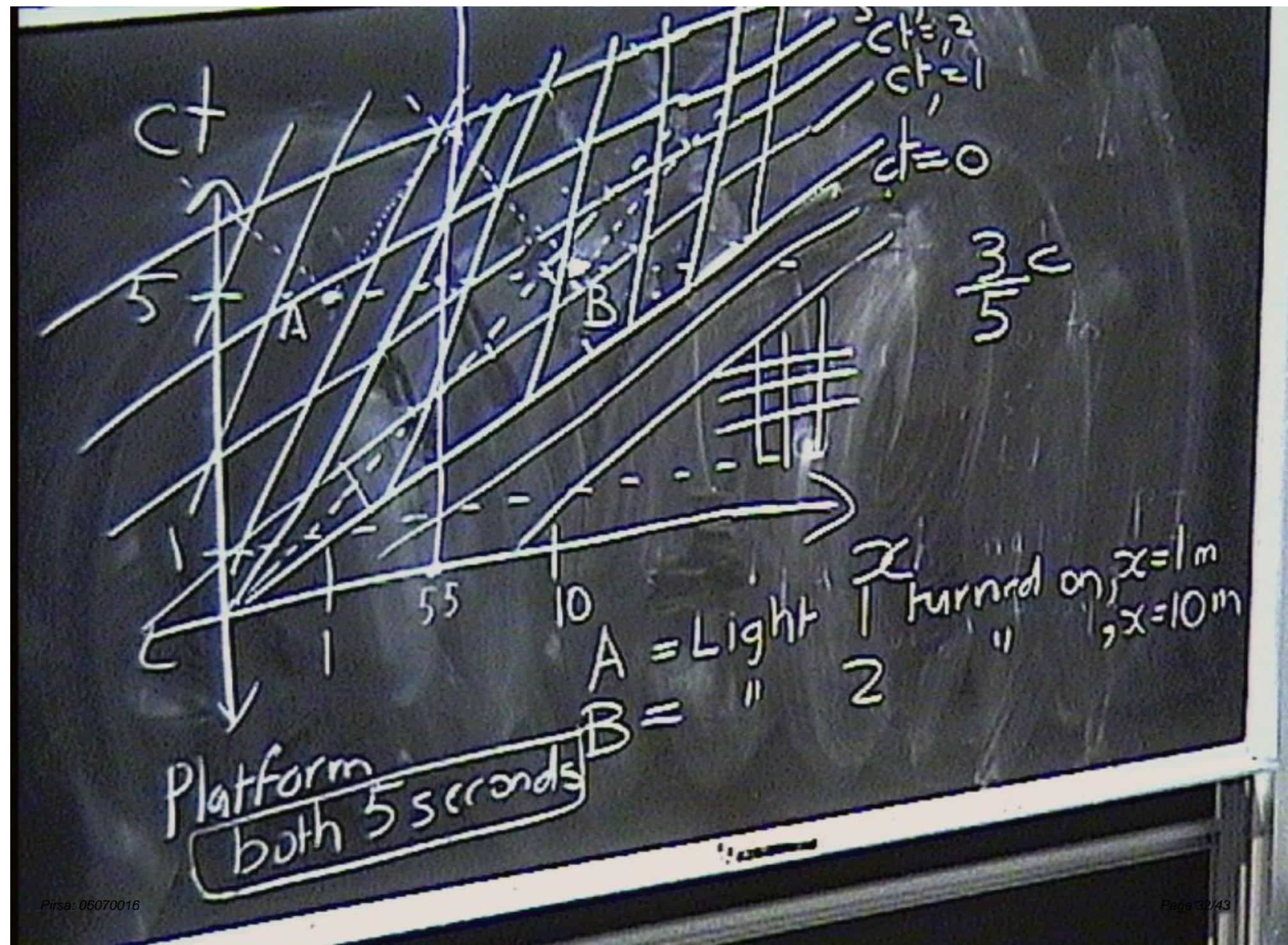


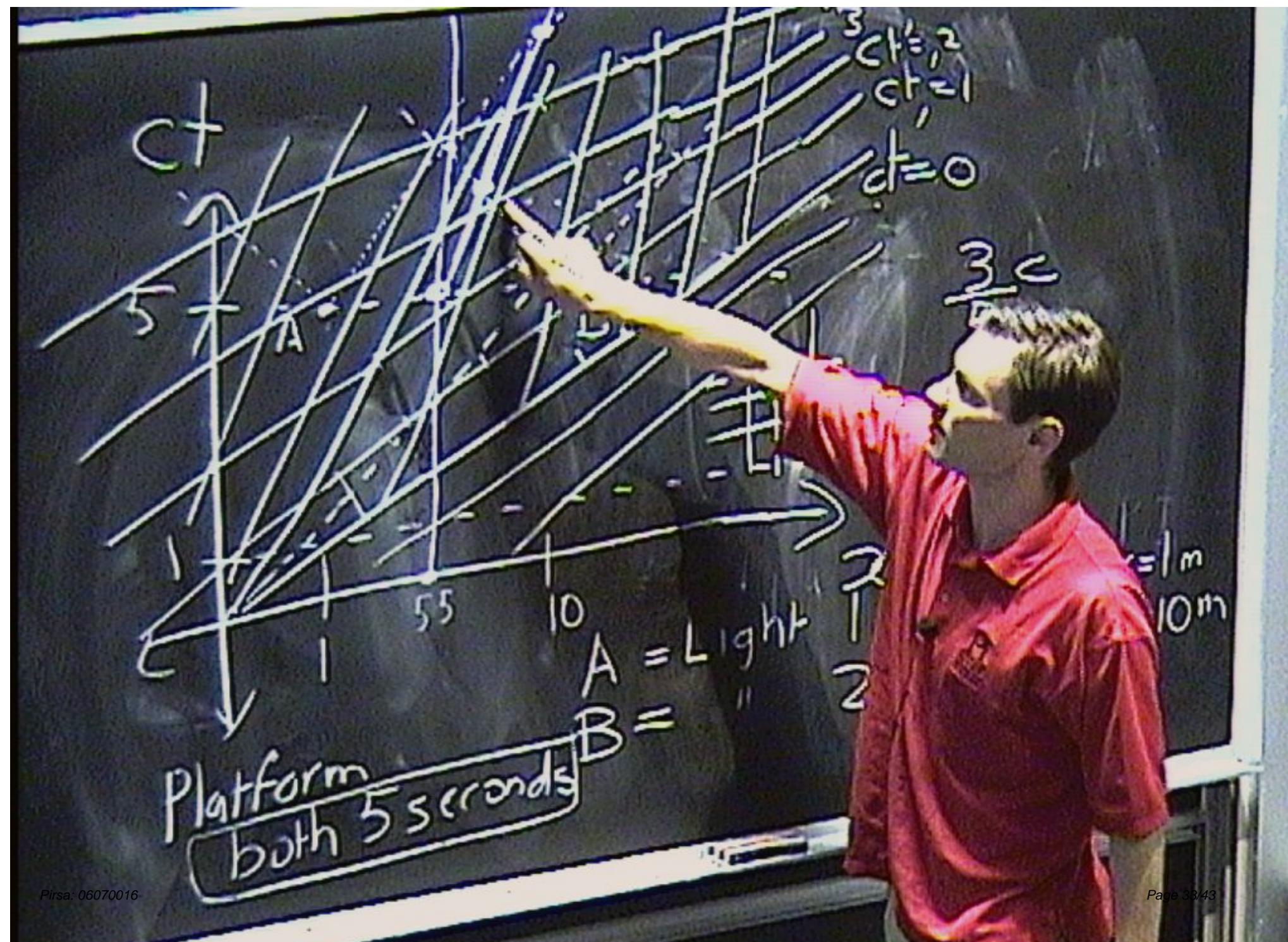












Platform
bottom

A = Light

2

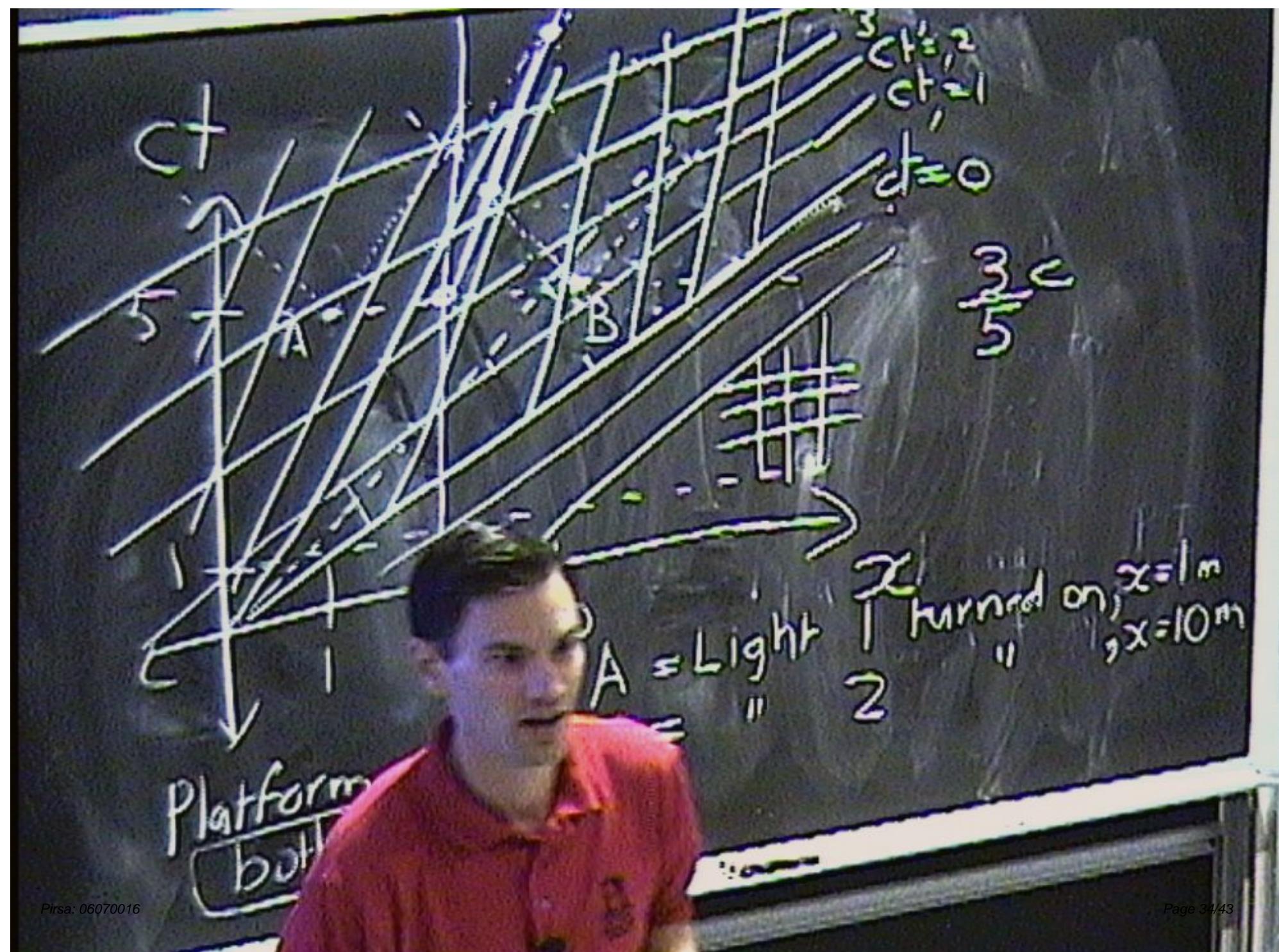
X turned on, $x=1m$
 $, x=10m$

ct

$ct=2$
 $ct=1$

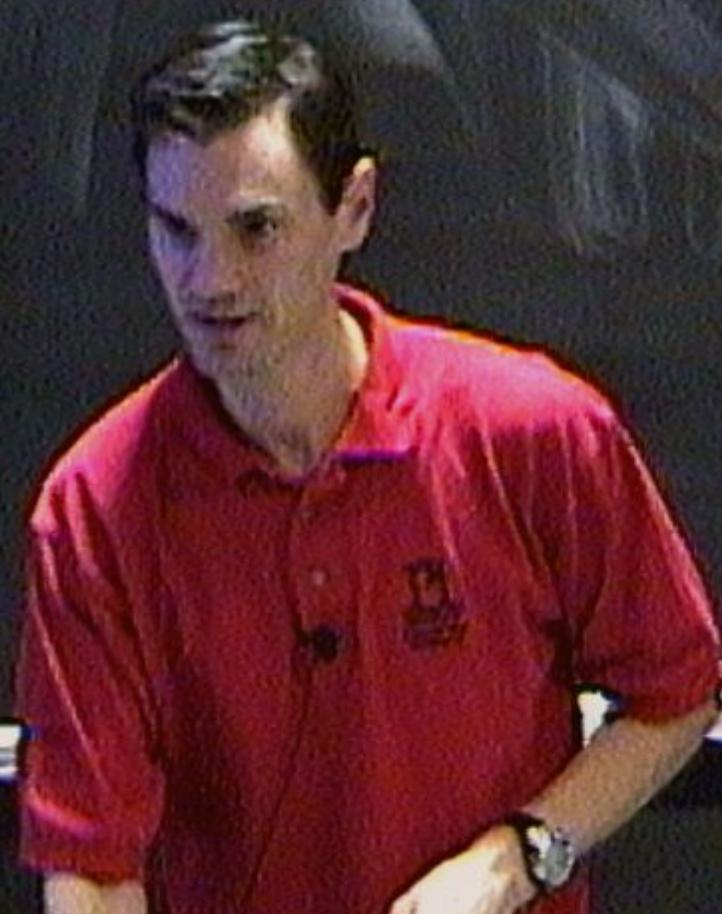
$d=0$

$\frac{3}{5}c$





EARTH





EAR





