HARVARD PROJECT PHYSICS
Overhead Projection Transparencies
UNIT 3

Harvard Project Physics
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Unit 3

T19

T-19 One-Dimensional Collisions

Facsimiles of stroboscopic photographs involving two-body collisions in one dimension are provided in this transparency. Two events which are useful in discussing the principle of conservation of momentum are presented. The first event (T19-A) shows ball A coming in from the right with ball B initially at rest. Both move off to the left after the collision. Event 2 (T19-B) shows ball B coming in from the left with ball A initially at rest. Overlay T19-C shows the directions after collision: ball B moves to the left and ball A moves to the right.

You may make measurements directly on the transparency or you may have students make measurements from images projected onto a chalkboard or wall.

EVENT 1

Before

Ball A	Ball B
d = 4.05 cm (from photo)	
$d = 4.05 \text{ cm} \times \frac{1 \text{ m}}{11.65 \text{ cm}} = 0.348 \text{ m}$	
$\overleftarrow{v} = 3.48$ m/sec	
$m\overleftarrow{v} = 1.85$ kg-m/sec	$m\overleftarrow{v} = 0$
$\frac{1}{2} m\overleftarrow{v}^2 = 3.22$ joules	

After

Ball A	Ball B
d′ = 1.1 cm (from photo)	d′ = 4.5 cm (from photo)
d′ = 0.0945 m (actual)	d′ = 0.386 m (actual)
$\overleftarrow{v}' = 0.945$ m/sec	$\overleftarrow{v}' = 3.86$ m/sec
$m\overleftarrow{v}' = 0.503$ kg-m/sec	$m\overleftarrow{v}' = 1.35$ kg-m/sec
$\frac{1}{2} m\overleftarrow{v}'^2 = 0.237$ joules	$\frac{1}{2} m\overleftarrow{v}'^2 = 2.61$ joules

EVENT 2

Before

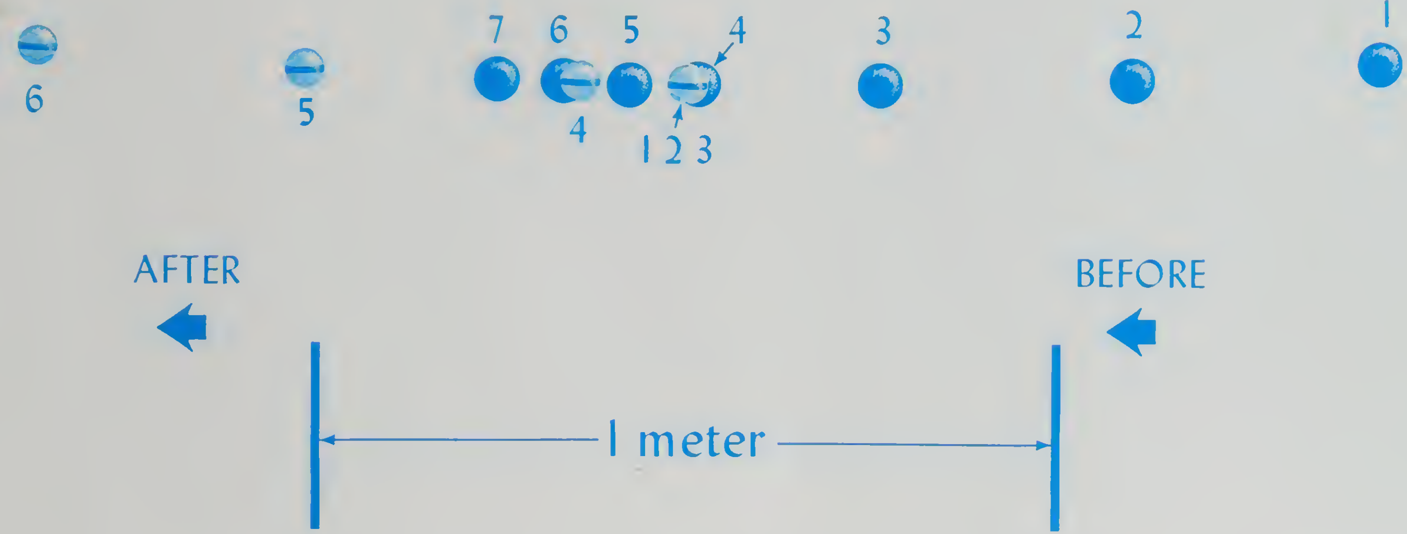
Ball A	Ball B
	d = 4.5 cm (from photo)
	d = 0.325 m (actual)
	$\overleftarrow{v} = 3.25$ m/sec
	$m\overleftarrow{v} = 1.14$ kg-m/sec
$m\overleftarrow{v} = 0$	$\frac{1}{2} m\overleftarrow{v}^2 = 1.85$ joules

After

Ball A	Ball B
d′ = 3.4 cm (from photo)	d′ = 0.6 cm (from photo)
d′ = 0.245 (actual)	d′ = 0.0434 m (actual)
$\overleftarrow{v}' = 2.45$ m/sec	$\overleftarrow{v}' = 0.434$ m/sec
$m\overleftarrow{v}' = 1.31$ kg-m/sec	$m\overleftarrow{v}' = 0.152$ kg-m/sec
$\frac{1}{2} m\overleftarrow{v}'^2 = 1.61$ joules	$\frac{1}{2} m\overleftarrow{v}'^2 = 0.033$ joules

Event 1 $\Delta t = 0.1$ sec

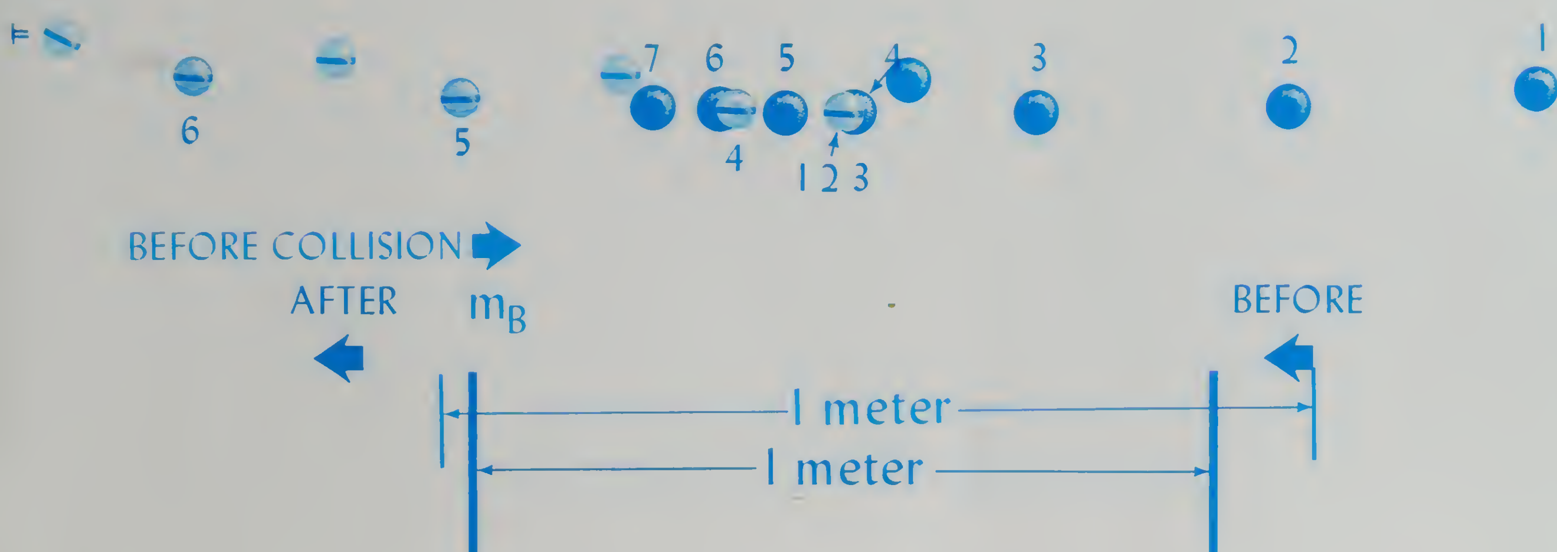
$m_B = 0.350$ kg $m_A = 0.532$ kg



A
B

Event 2 $\Delta t = 0.1$ sec

$m_B = 0.350$ kg $m_A = 0.532$ kg



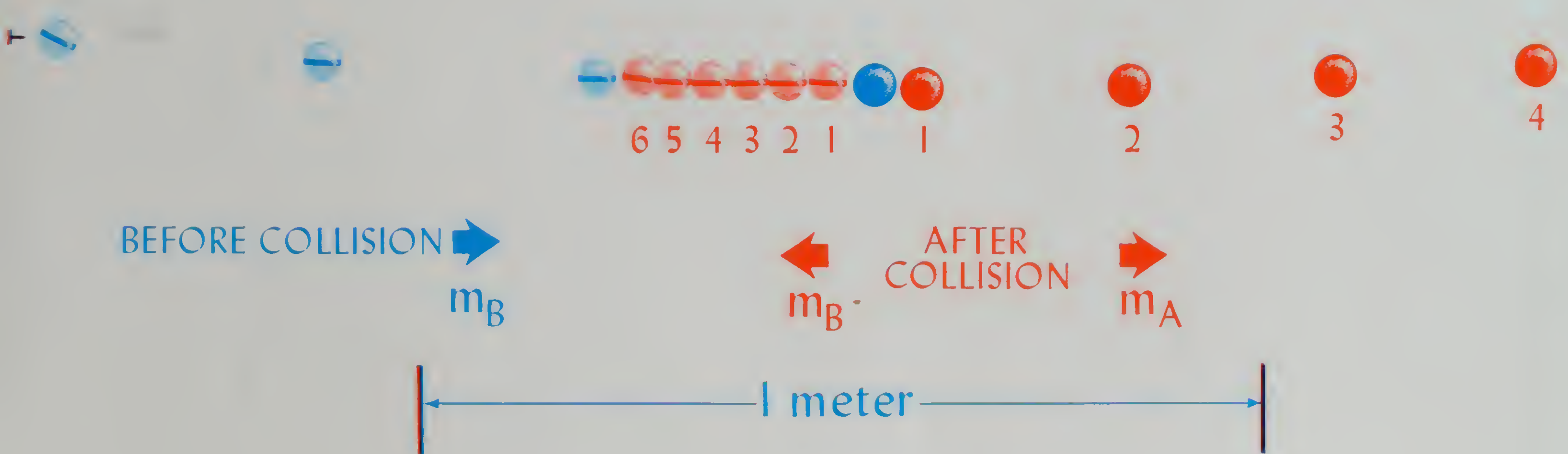
B
C

Event 2

$\Delta t = 0.1$ sec

$m_B = 0.350$ kg

$m_A = 0.532$ kg



T20

T-20 Equal Mass Two-Dimensional Collisions

This transparency and T21 and T22 are intended to accompany the film loops and stroboscopic photographs dealing with the two-dimensional collisions discussed in Chapter 9 of the text. You may wish to distribute stroboscopic photograph No. 69 to the students and proceed to explain the technique required in determining momentum before and after the collision as your students follow with their own photographs. Transparencies T21 and T22 may be used in a similar manner, or you may wish to assign stroboscopic photographs 73 and 74 for homework. You may then use T21 and T22 on the following day to show the students the correct solution. Alternately you may have students work independently or in groups directly on the transparencies or on a projected image on a chalkboard.

Overlay A Shows a facsimile of photograph 69. The impinging ball (mass = 0.367 kg) approaches from the upper left of the picture while the target ball (mass = 0.367 kg) which was originally stationary proceeds to the right after the collision. The distance between the two marks at the lower portion of the transparency represents one meter.

Overlay B Shows the first step in computing the momentum quantities. Determine the velocities by measuring the distances in the indicated places and divide these by the time interval ($\Delta t = 0.05$ sec). The momentum is then computed by multiplying these velocity values by the respective masses. You may now remove Overlay A and proceed with the others.

Overlay C Shows momentum vectors before and after collision drawn to a scale of 7cm = 1 kg-m/sec.

Overlay D Shows the resultant momentum vector $\vec{P}'$ after the collision. It can be seen to be approximately equal to the momentum before collision $\vec{P}$.

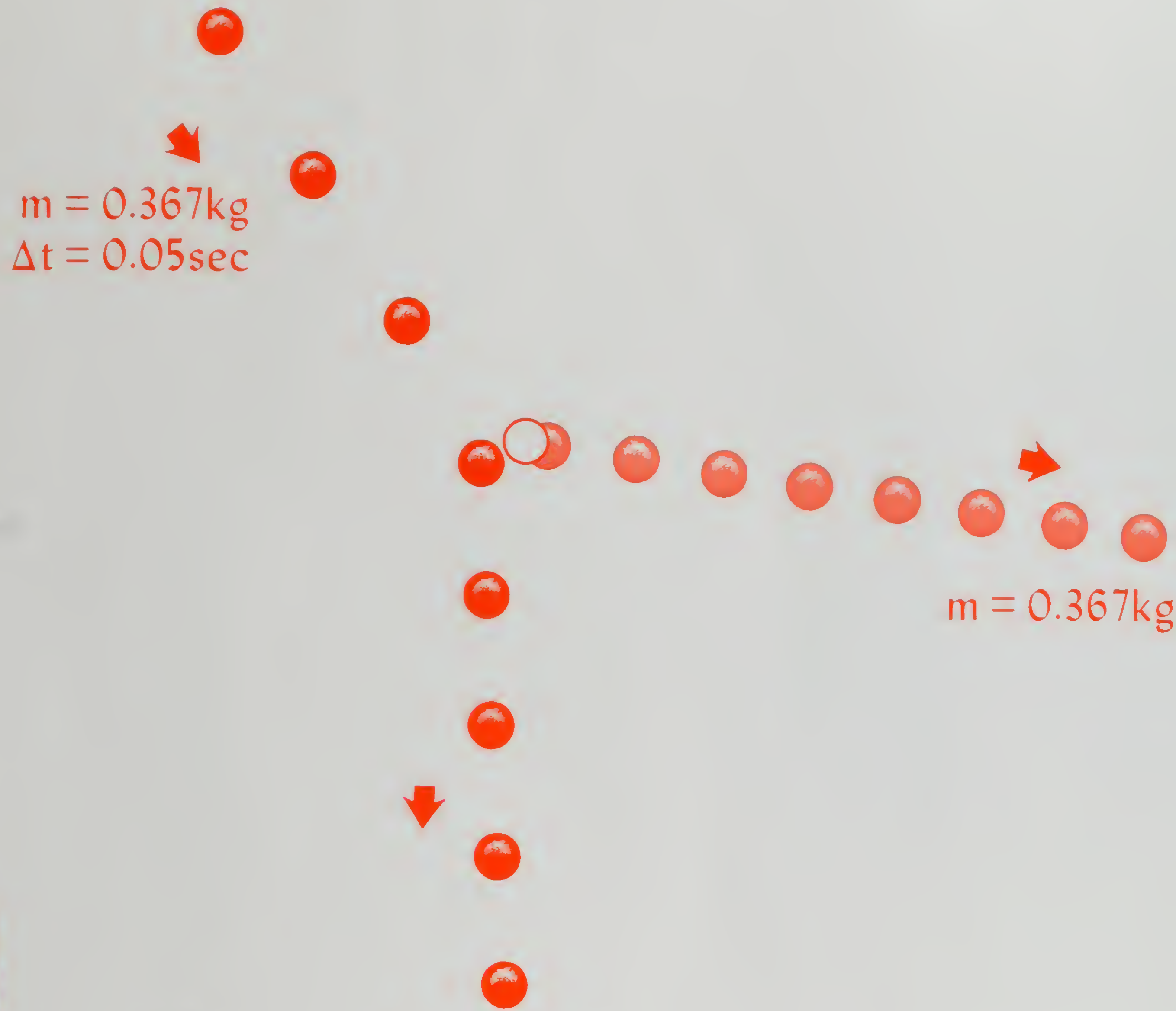
BEFORE COLLISION

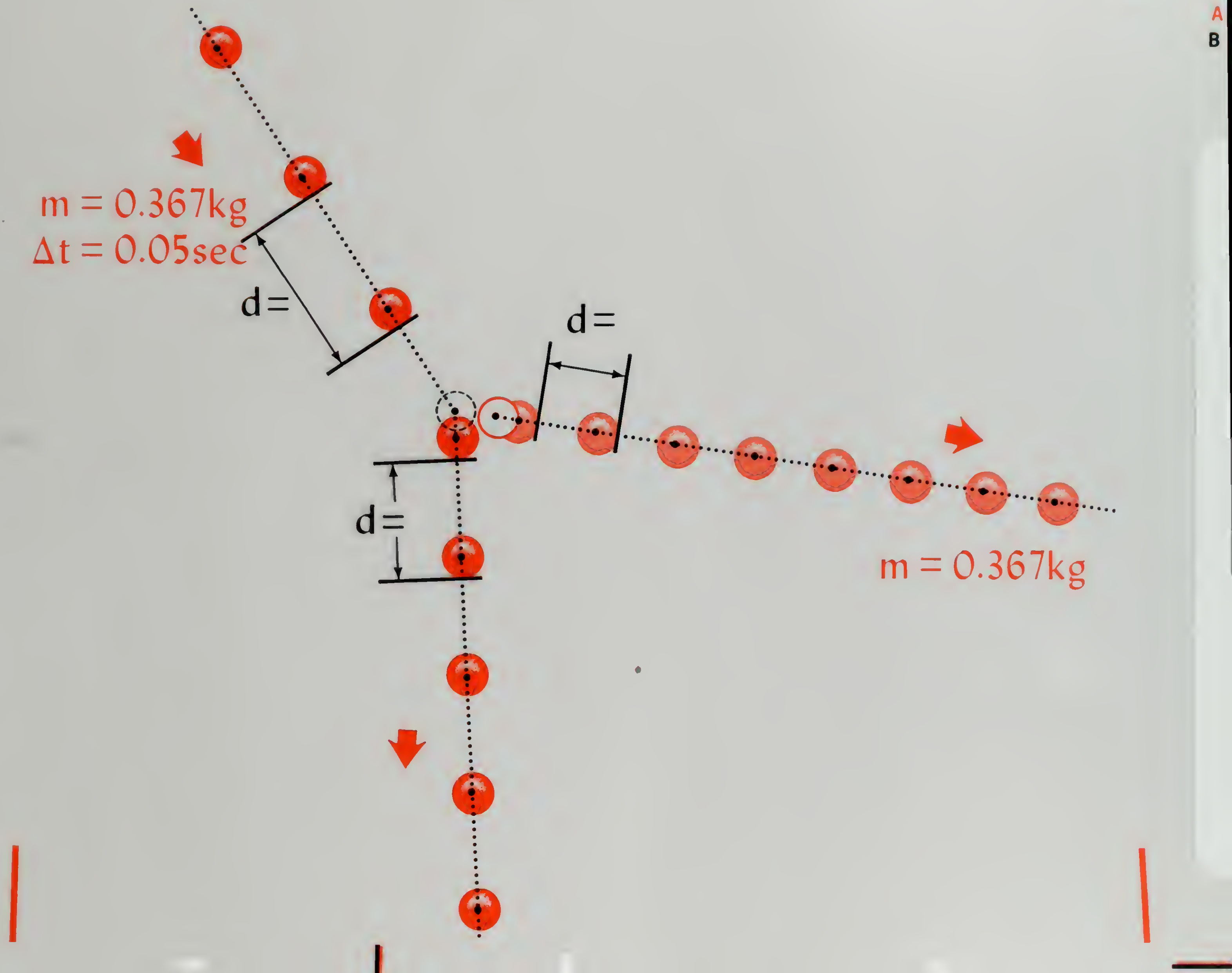
Impinging Ball		Target Ball
m = 0.367 kg		
d = 3.20 cm (from photo)		m = 0.367 kg
	Scale: 1 meter = 22.8 cm	
$d = 3.20\text{ cm} \times \frac{1}{22.8}\frac{\text{m}}{\text{cm}}$		
d = 0.141 m (actual)		
	$\Delta t = 0.05$ sec	
$\vec{v} = 2.81$ m/sec		$\vec{v} = 0$
$m\vec{v} = 1.03$ kg-m/sec		$m\vec{v} = 0$
$\frac{1}{2} m\vec{v}^2 = 1.45$ joules		$\frac{1}{2} m\vec{v}^2 = 0$

AFTER COLLISION

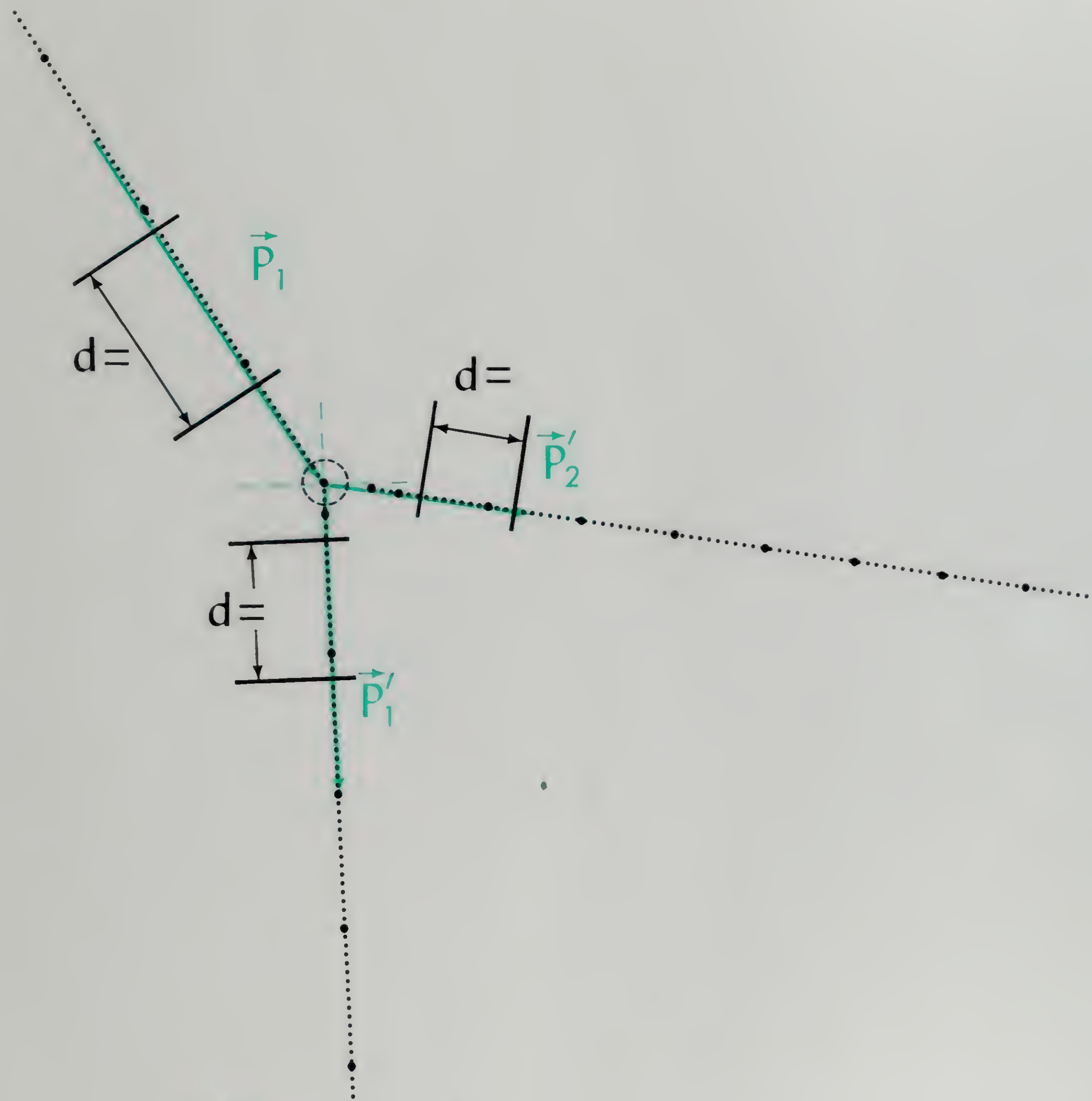
d′ = 2.40 cm (from photo)	d′ = 1.65 cm (from photo)
d′ = 0.105 m (actual)	d′ = 0.0725 m (actual)
$\vec{v}' = 2.10$ m/sec	$\vec{v}' = 1.45$ m/sec
$m\vec{v}' = 0.771$ kg-m/sec	$m\vec{v}' = 0.532$ kg-m/sec
$\frac{1}{2} m\vec{v}'^2 = 0.810$ joules	$\frac{1}{2} m\vec{v}'^2 = 0.386$ joules

($m\vec{v}$ scale: 7 cm = 1 kg-m/sec)

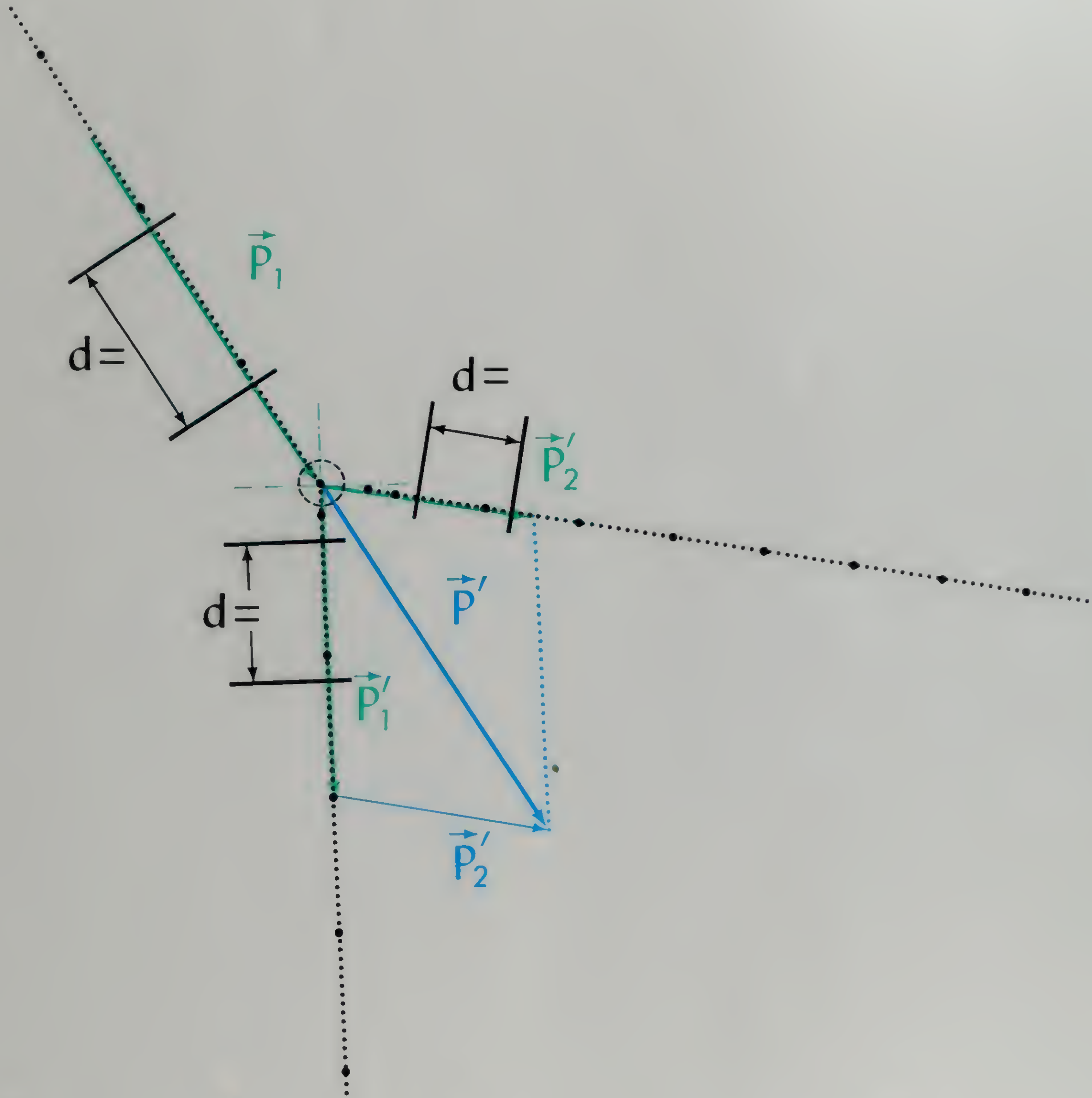

m = 0.367kg
Δt = 0.05sec
m = 0.367kg


A
B
m = 0.367kg
Δt = 0.05sec
d=
d=
d=
m = 0.367kg

B
C



B
C
D



'21

T-21 Unequal Mass Two-Dimensional Collisions

This transparency is facsimile of stroboscopic photograph 74 which shows the collision of spheres of unequal mass both of which are moving before collision.

Overlay A Shows a sphere of mass 1.80 kg approaching from the upper left and a sphere of mass 4.29 kg approaching from the upper right. After the collision the less massive ball proceeds to the lower left while the larger ball travels toward the lower central portion of the picture. The time interval shown is 0.10 sec; the scale is indicated by the one meter markers at the bottom of the overlay.

Overlay B Shows the first step in computing the momentum quantities. Determine the four velocities by measuring the distances in the indicated places and divide these by the time interval ($\Delta t = 0.10$ sec). The momentum is then computed by multiplying these velocity values by their respective masses. You may now remove Overlay A and proceed with the others.

Overlay C Shows momentum vectors drawn to a scale of 1 cm = 1 kg-m/sec.

Overlay D Shows the resultant momentum vector before collision $\vec{P}$ and the resultant momentum vector after collision $\vec{P}'$ to be equal.

BEFORE COLLISION

Small Ball	Large Ball
$m = 1.80$ kg	$m = 4.29$ kg
$d = 6.40$ cm (from photo)	$d = 4.25$ cm (from photo)

Scale: 1 meter = 22.8 cm

$$d = 6.40 \text{ cm} \times \frac{1}{22.8} \frac{\text{m}}{\text{cm}}$$

Small Ball	Large Ball
$d = 0.281$ m (actual)	$d = 0.187$ m (actual)

$\Delta t = 0.10$ sec

Small Ball	Large Ball
$\vec{v} = 2.81$ m/sec	$\vec{v} = 1.87$ m/sec
$m\vec{v} = 5.06$ kg-m/sec	$m\vec{v} = 8.03$ kg-m/sec
$\frac{1}{2} m\vec{v}^2 = 7.11$ joules	$\frac{1}{2} m\vec{v}^2 = 7.50$ joules

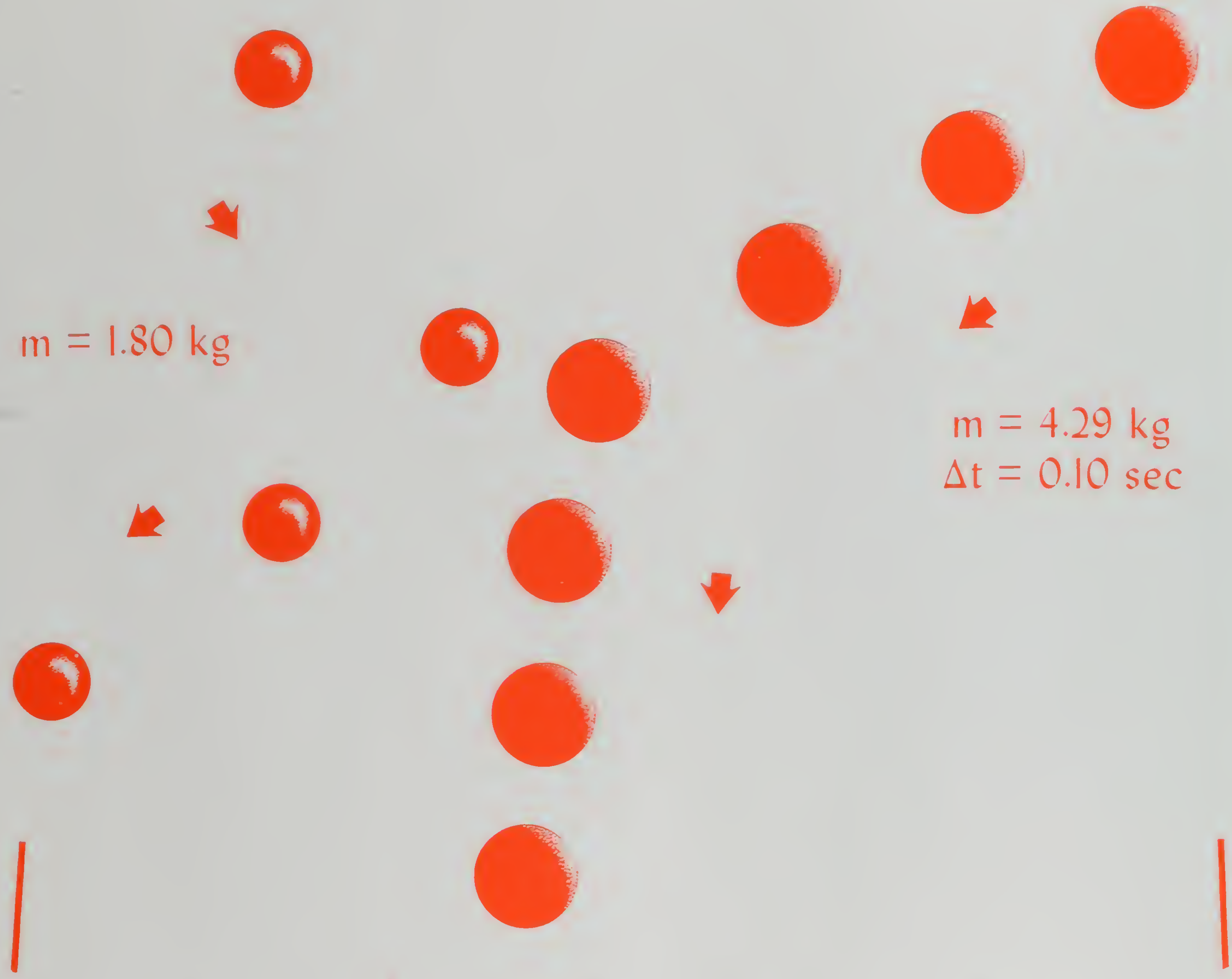
($m\vec{v}$ scale: 1 cm = 1 kg-m/sec)

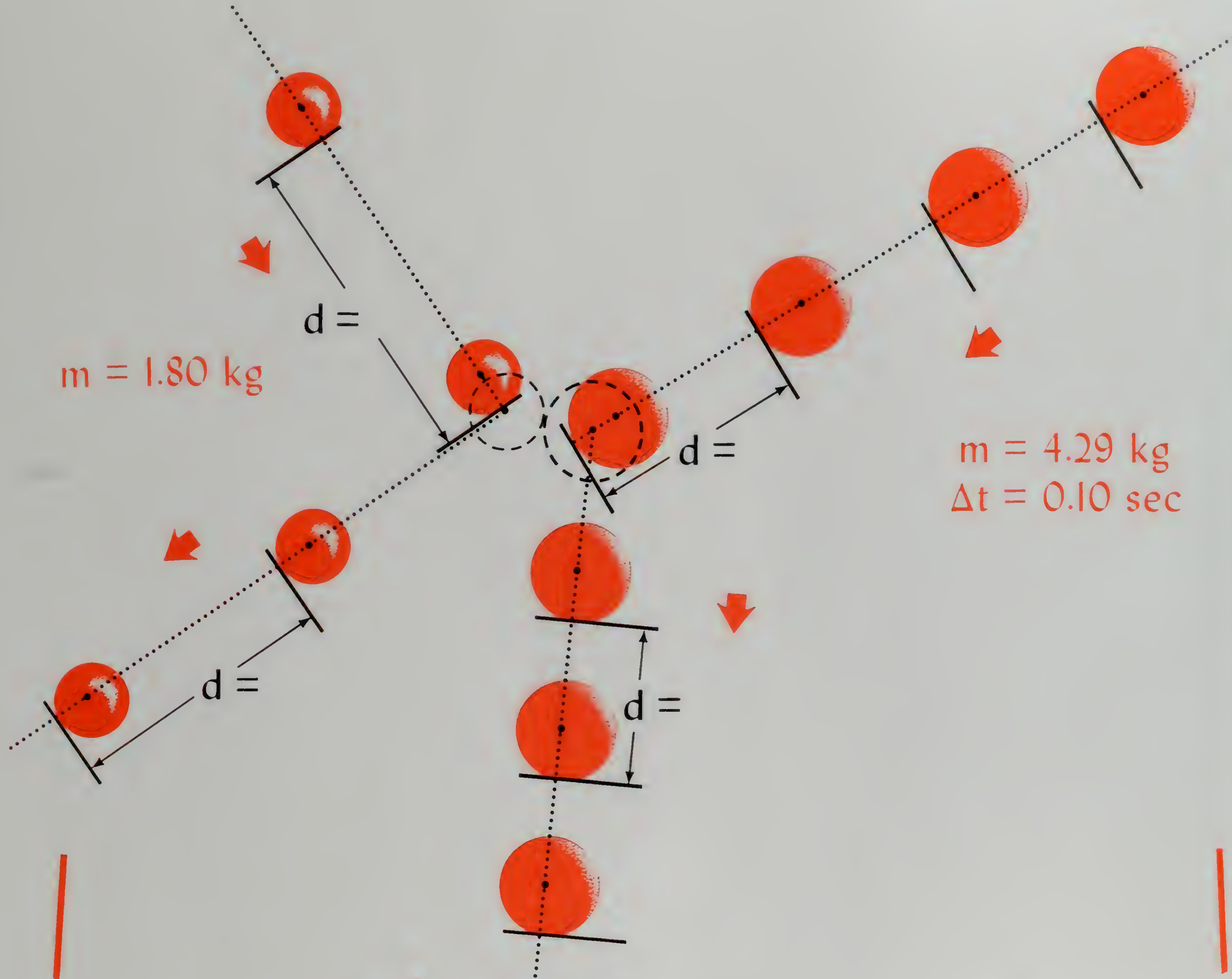
AFTER COLLISION

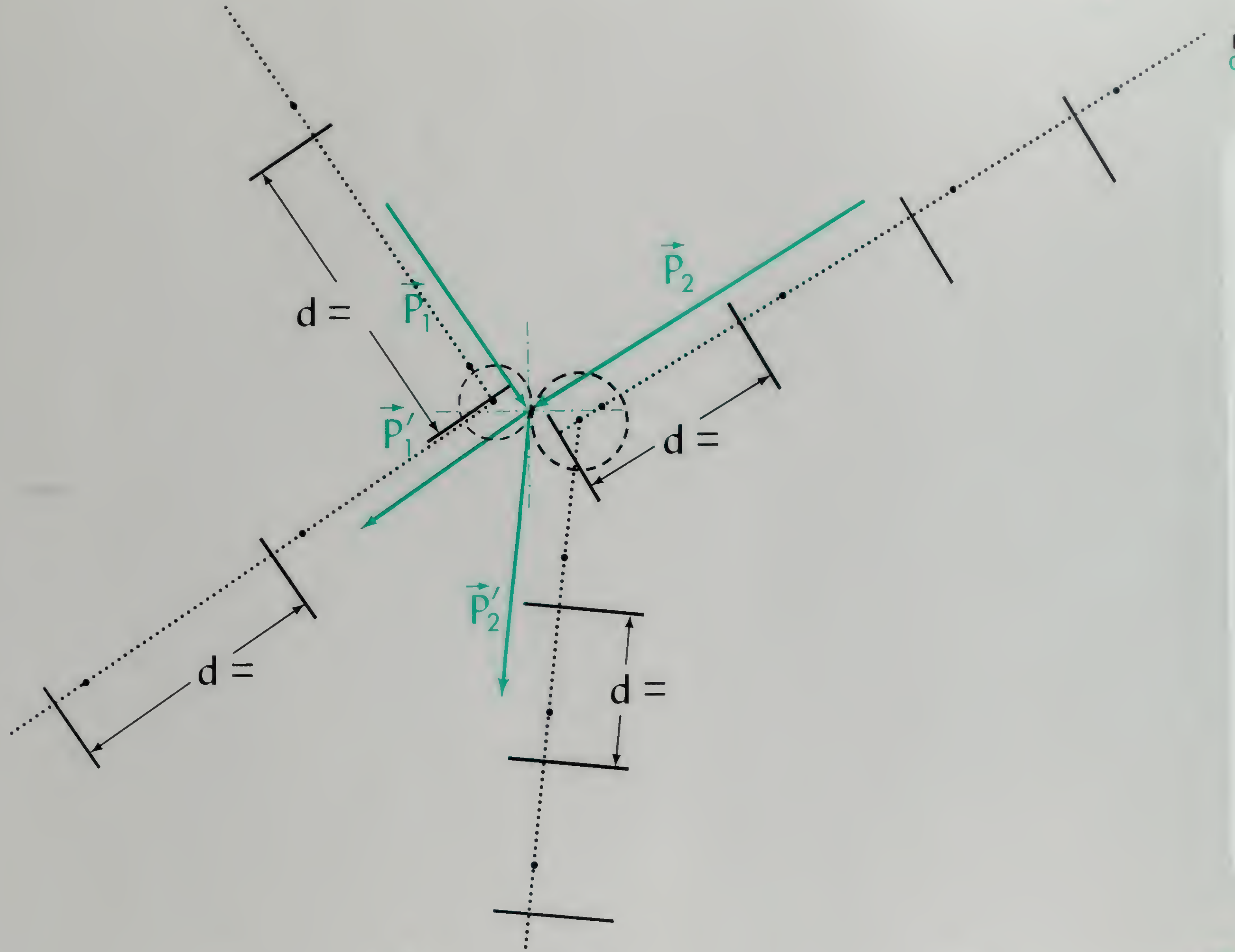
Small Ball	Large Ball
$d' = 5.30$ cm (from photo)	$d' = 3.15$ cm (from photo)
$d' = 0.232$ m (actual)	$d' = 0.138$ m (actual)
$\vec{v}' = 2.32$ m/sec	$\vec{v}' = 1.38$ m/sec
$m\vec{v}' = 4.18$ kg-m/sec	$m\vec{v}' = 5.79$ kg-m/sec $\Sigma 9.97$
$\frac{1}{2} m\vec{v}'^2 = 4.85$ joules	$\frac{1}{2} m\vec{v}'^2 = 3.92$ joules $\Sigma 8.77$;

A profitable discussion might focus on:

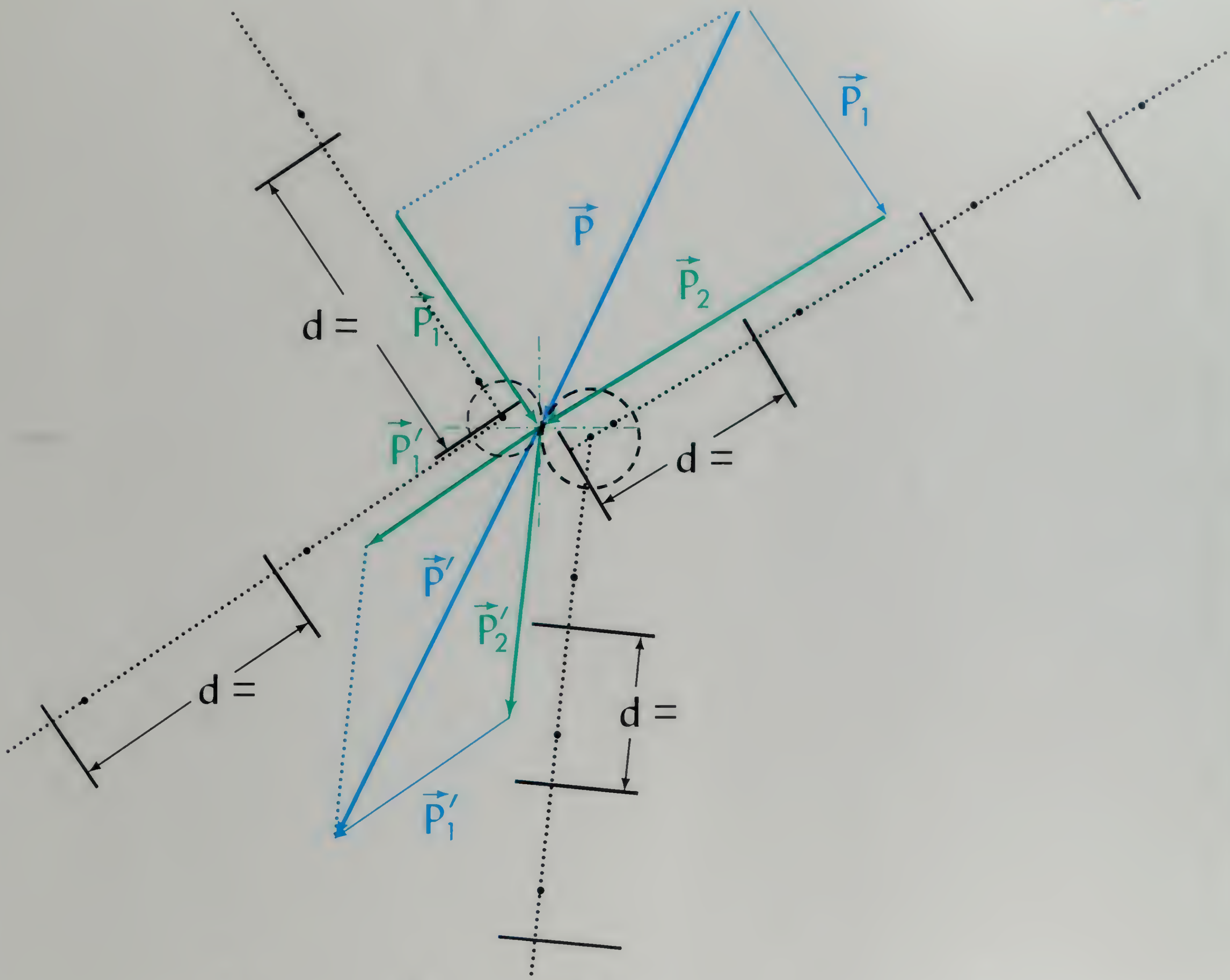
1. What became of the "lost" momentum?
2. Are we likely to observe perfectly elastic collisions between large objects?
3. What became of the "lost" kinetic energy?
4. If we add the two "before" momentum vectors and compare them to the sum of the "after" vectors, is momentum conserved?
5. Can the kinetic energies be added vectorially?


m = 1.80 kg
m = 4.29 kg
Δt = 0.10 sec


A
B
d =
m = 1.80 kg
d =
m = 4.29 kg
Δt = 0.10 sec
d =
d =


B
C
d =
$\vec{P}_1$
$\vec{P}_2$
$\vec{P}_1'$
d =
d =
$\vec{P}_2'$
d =

B
C
D



T-22 Inelastic Two-Dimensional Collisions

T22

This transparency is a facsimile of stroboscopic photograph 73. It depicts an inelastic collision between spheres of equal mass (0.50 kg). The spheres are covered with plasticene, a clay-like material.

Overlay A Shows one sphere approaching from the left and one approaching from the right. After the collision they proceed as one body to the lower right. The time interval is 0.10 sec.

Overlay B Shows the first step in computing the momentum quantities. Determine the three velocities by measuring the distances in the indicated places and divide these by the time interval ($\Delta t = 0.10$ sec). The momentum is then computed by multiplying these velocity values by their respective masses. You may now remove Overlay A and proceed with the others.

Overlay C Shows momentum vectors drawn to a scale of 7 cm = 1 kg-m/sec.

Overlay D Shows the resultant momentum vector before collision to be equal to the momentum vector after collision.

BEFORE COLLISION

Left Ball	Right Ball
$m = 0.500$ kg	$m = 0.500$ kg
$d = 6.30$ cm (from photo)	$d = 4.55$ cm (from photo)
$d = 0.276$ m (actual)	$d = 0.199$ m (actual)

$\Delta t = 0.10$ sec

Left Ball	Right Ball
$\vec{v} = 2.76$ m/sec	$\vec{v} = 1.99$ m/sec
$m\vec{v} = 1.38$ kg-m/sec	$m\vec{v} = 0.999$ kg-m/sec
$\frac{1}{2} m\vec{v}^2 = 1.91$ joules	$\frac{1}{2} m\vec{v}^2 = 0.995$ joules

AFTER COLLISION

$m' = 1.00$ kg

$d' = 1.90$ cm (from photo)

$d' = 0.0834$ m (actual)

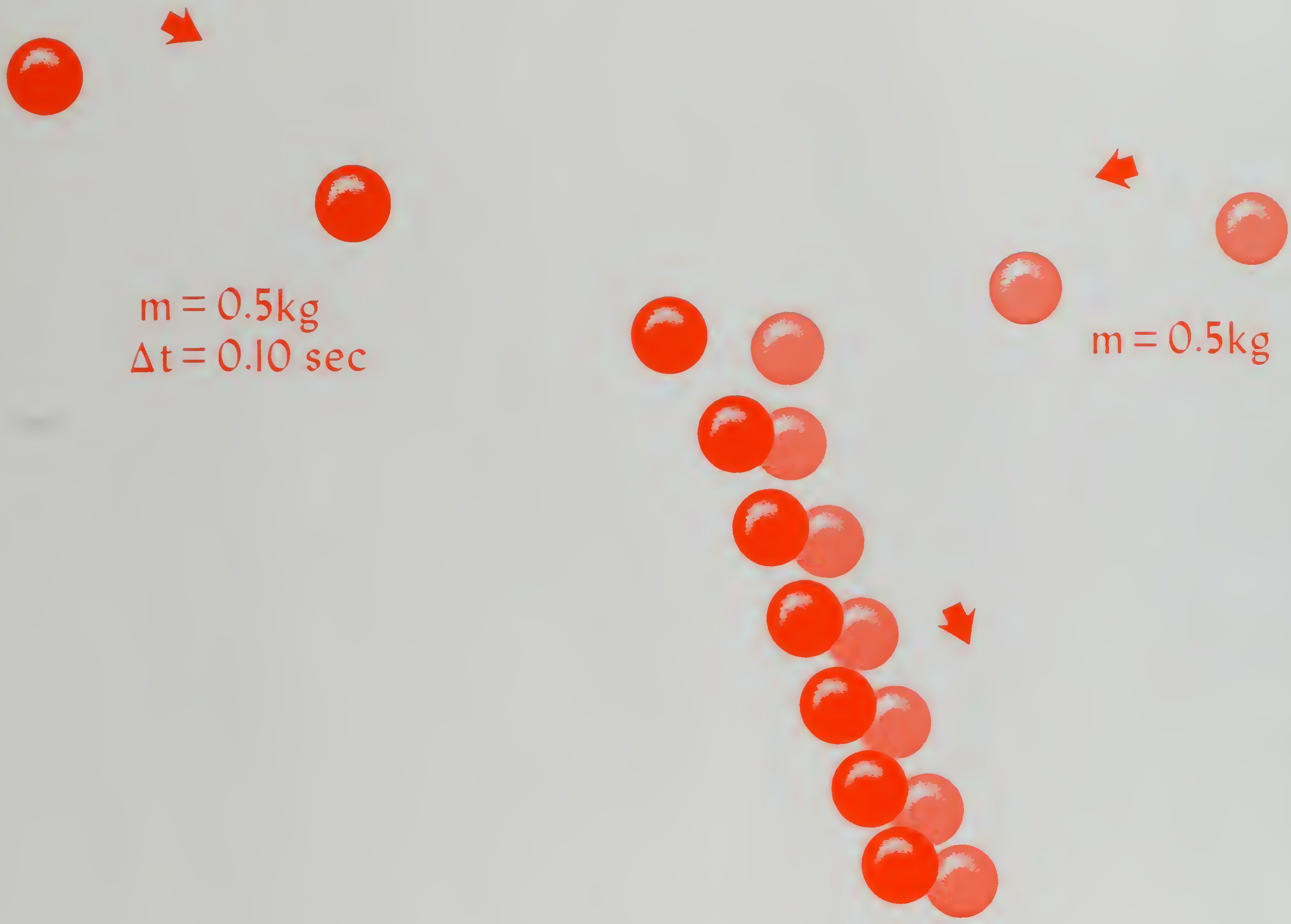
$\vec{v}' = 0.834$ m/sec

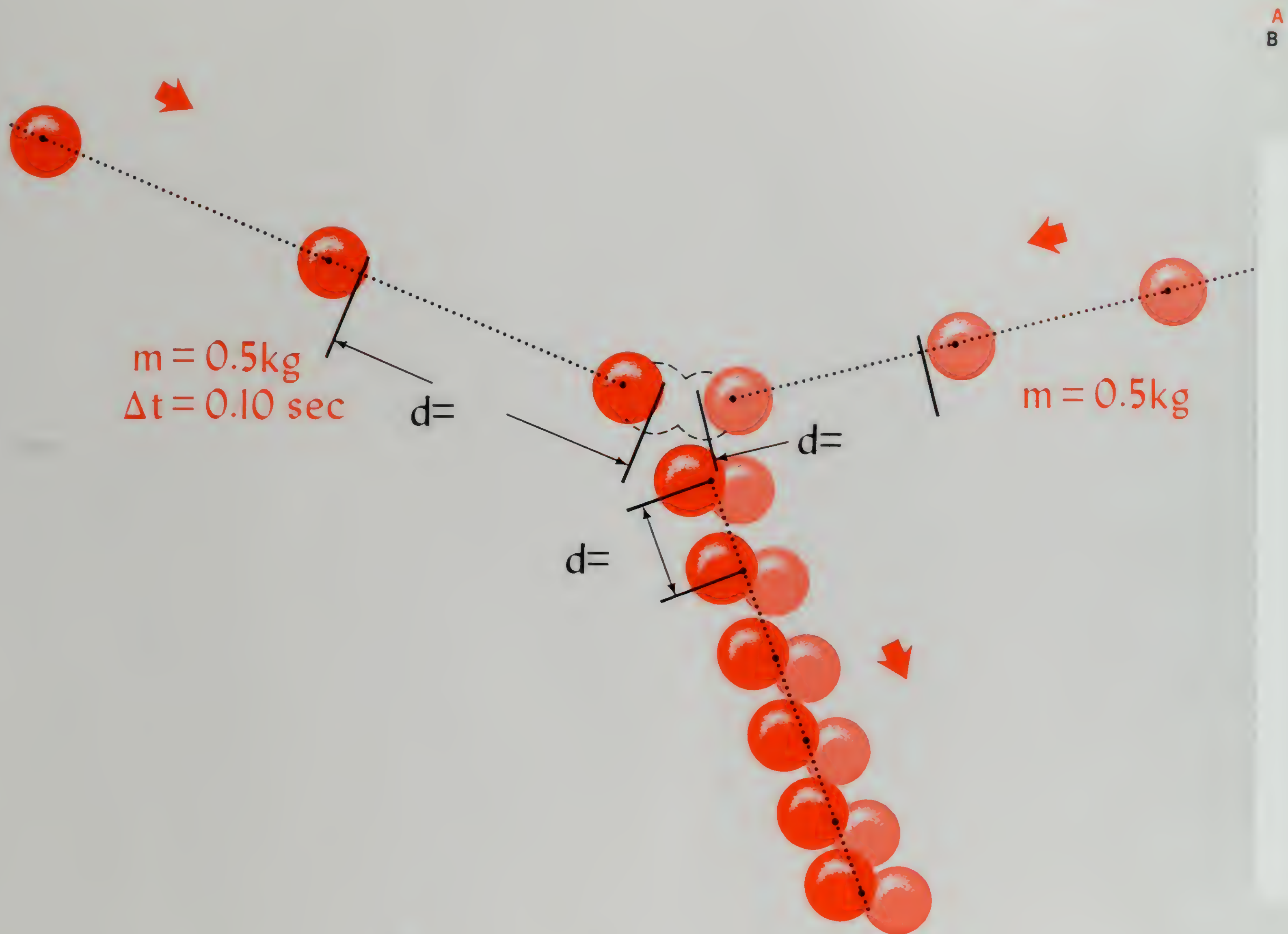
$m\vec{v}' = 0.834$ kg-m/sec

$\frac{1}{2} m\vec{v}'^2 = 0.348$ joules

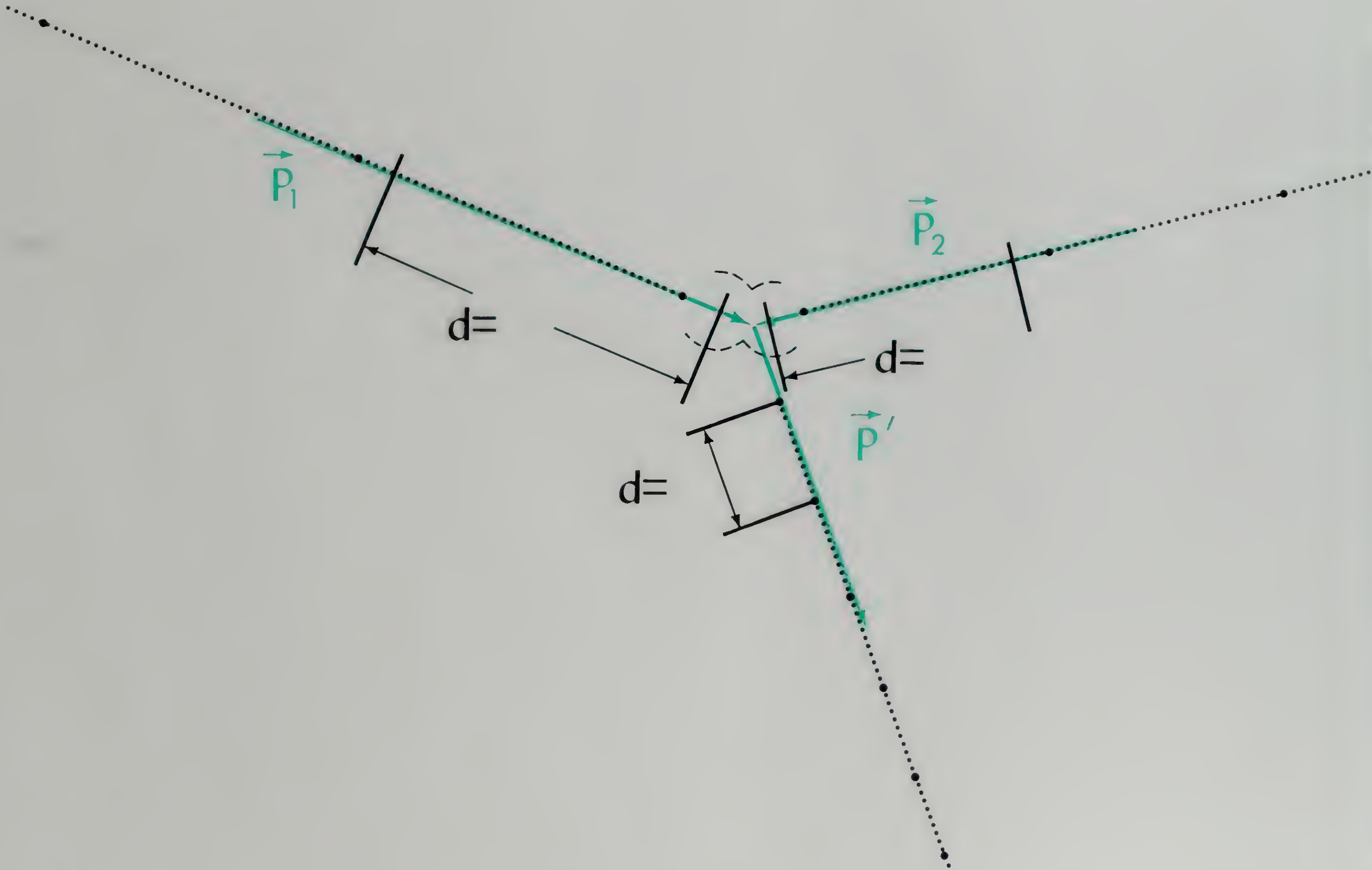
($m\vec{v}$ scale: 7 cm = 1 kg-m/sec)

A

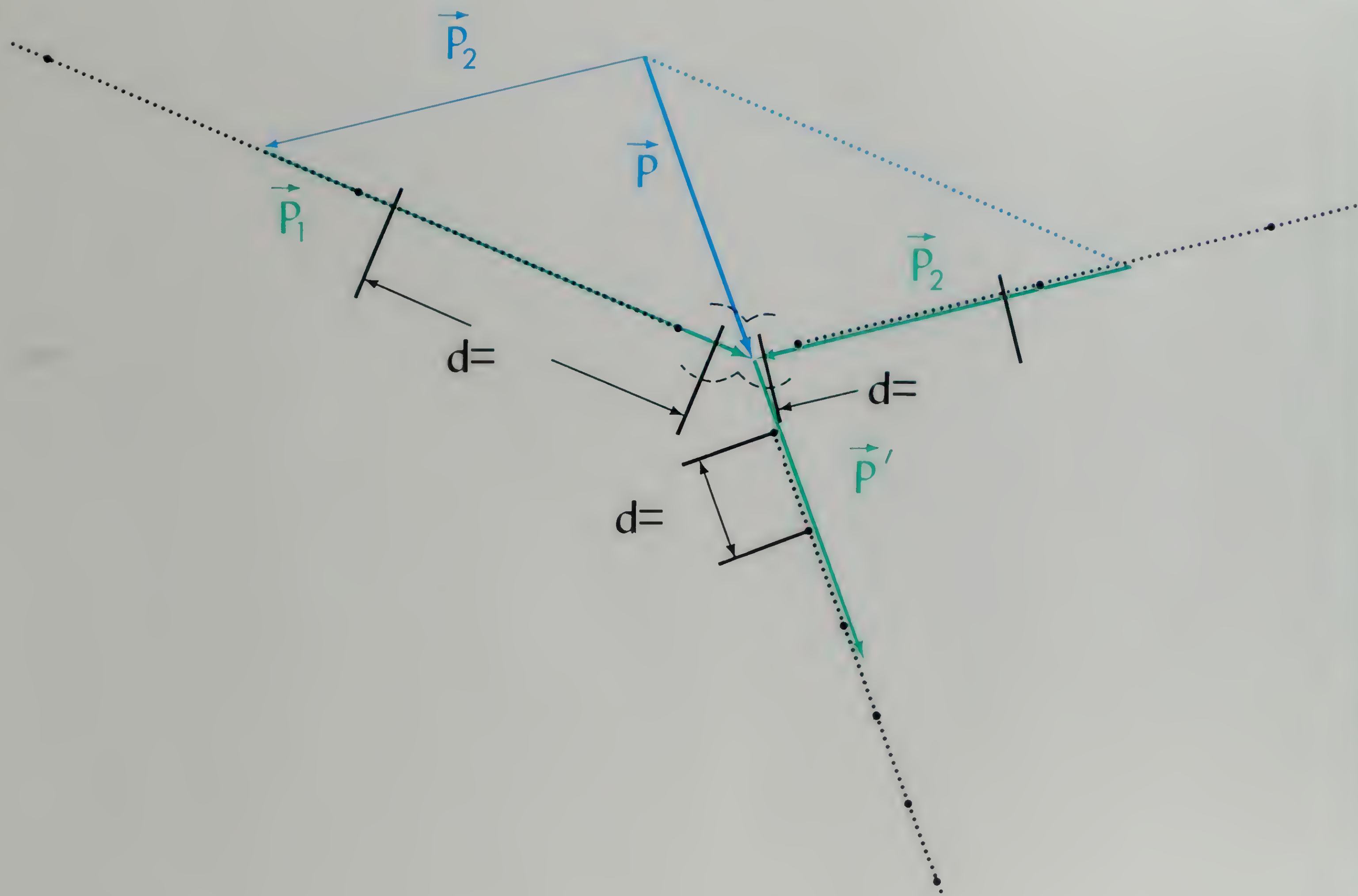



A
B
m = 0.5kg
Δt = 0.10 sec
d=
d=
d=
m = 0.5kg

B
C



B
C
D



T-23 Slow Collisions

This transparency is helpful in analyzing the stroboscopic photographs which your students will take of colliding carts in the Slow Collisions Experiment. It may also serve as a source of data if the student photographs are inadequate.

The events depicted in 3 separate overlays are as follows:

1- 4: 4.0 kg cart moving to right **before** collision

4-12: Same cart **during** collision

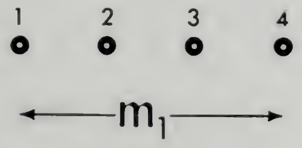
12-15: Same cart **after** collision

4-12: 2.0 kg target cart **during** collision

12-15: Same cart **after** collision

Image Number 12 is lighter in each level since one slit on the strobe disc is taped to produce a narrower aperture. This image represents the same instant of time for each cart. Data to be taken from this photograph include values for $m\vec{v}$ and $m\vec{v}^2$ **before, during,** and **after** the collision.

A



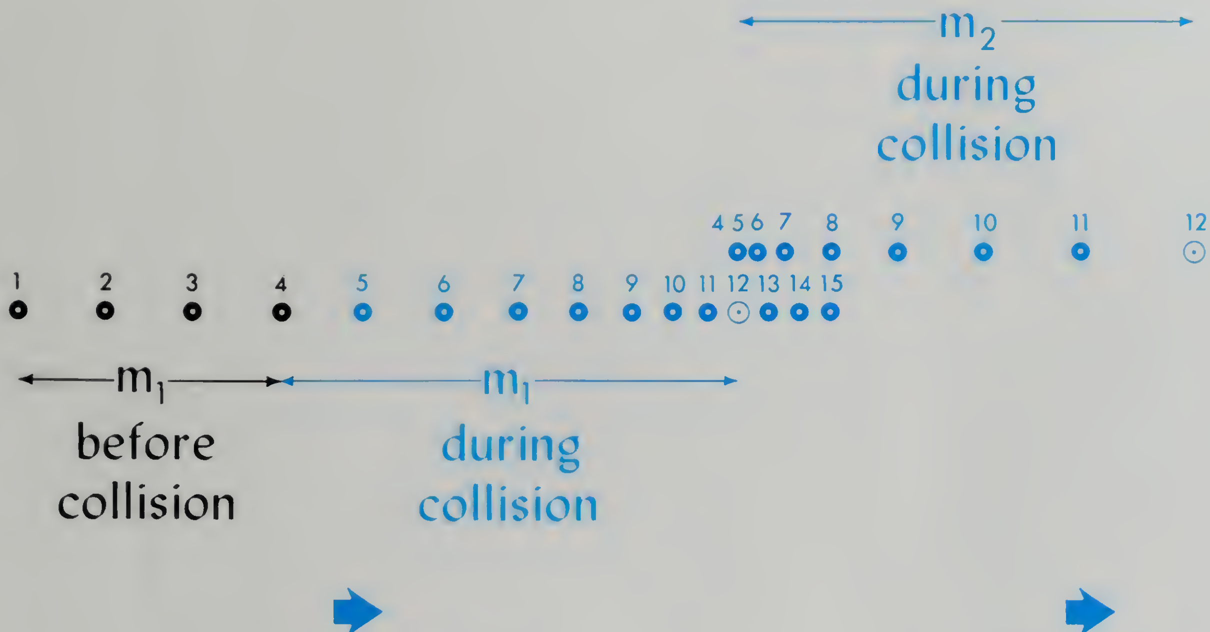
before collision

$m_1 = 4.0$ kg

$m_2 = 2.0$ kg

$$\Delta t = \frac{1}{60} \text{ sec}$$

1 cm = .05 m



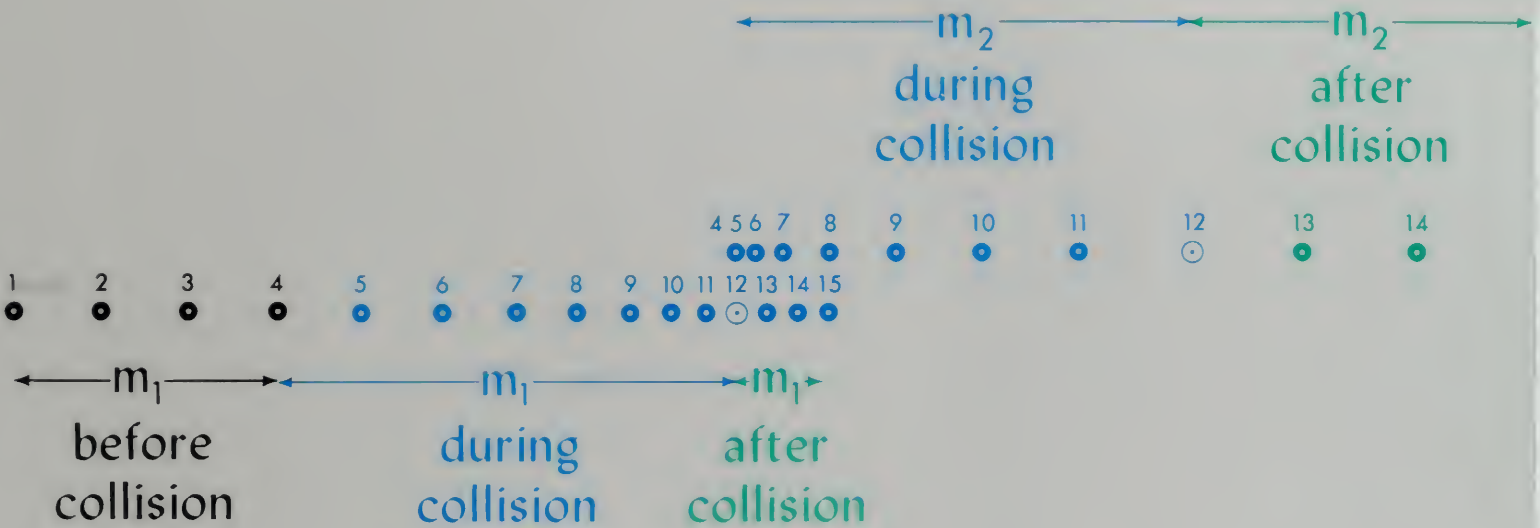
$m_1 = 4.0$ kg

$m_2 = 2.0$ kg

$$\Delta t = \frac{1}{60} \text{ sec}$$

1 cm = .05 m

A
B
C



$$m_1 = 4.0 \text{ kg}$$

$$m_2 = 2.0 \text{ kg}$$

$$\Delta t = \frac{1}{60} \text{ sec}$$

$$1 \text{ cm} = .05 \text{ m}$$

T-24 The Watt Engine

T24

This transparency will aid in discussing the contributions of Watt to the design of the steam engine. With the introduction of a separate external condenser the necessity of reheating the piston chamber is avoided. Also the engine's efficiency is increased and its fuel consumption is markedly decreased.

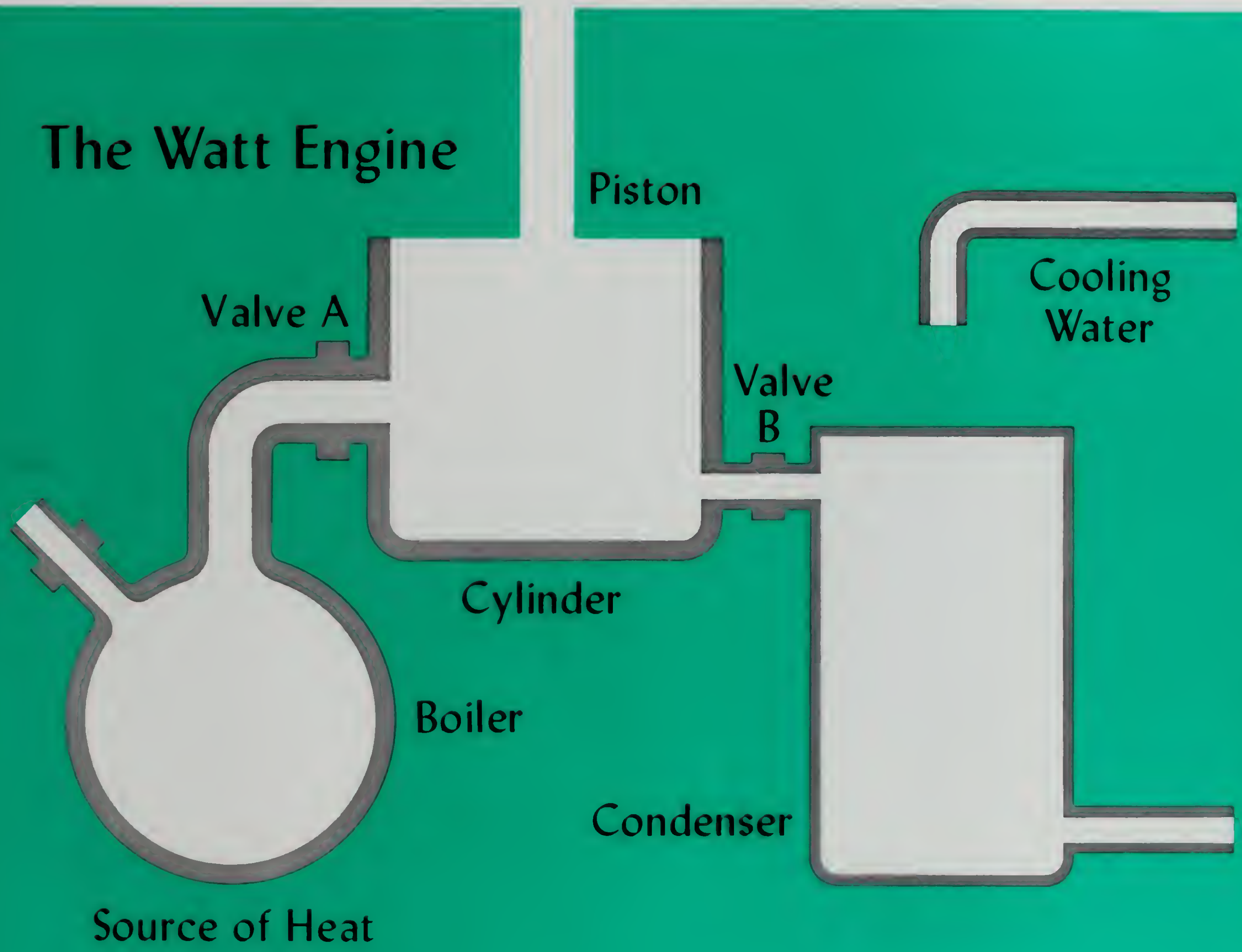
Overlay A Shows the general components of the Watt steam engine in a diagrammatic form.

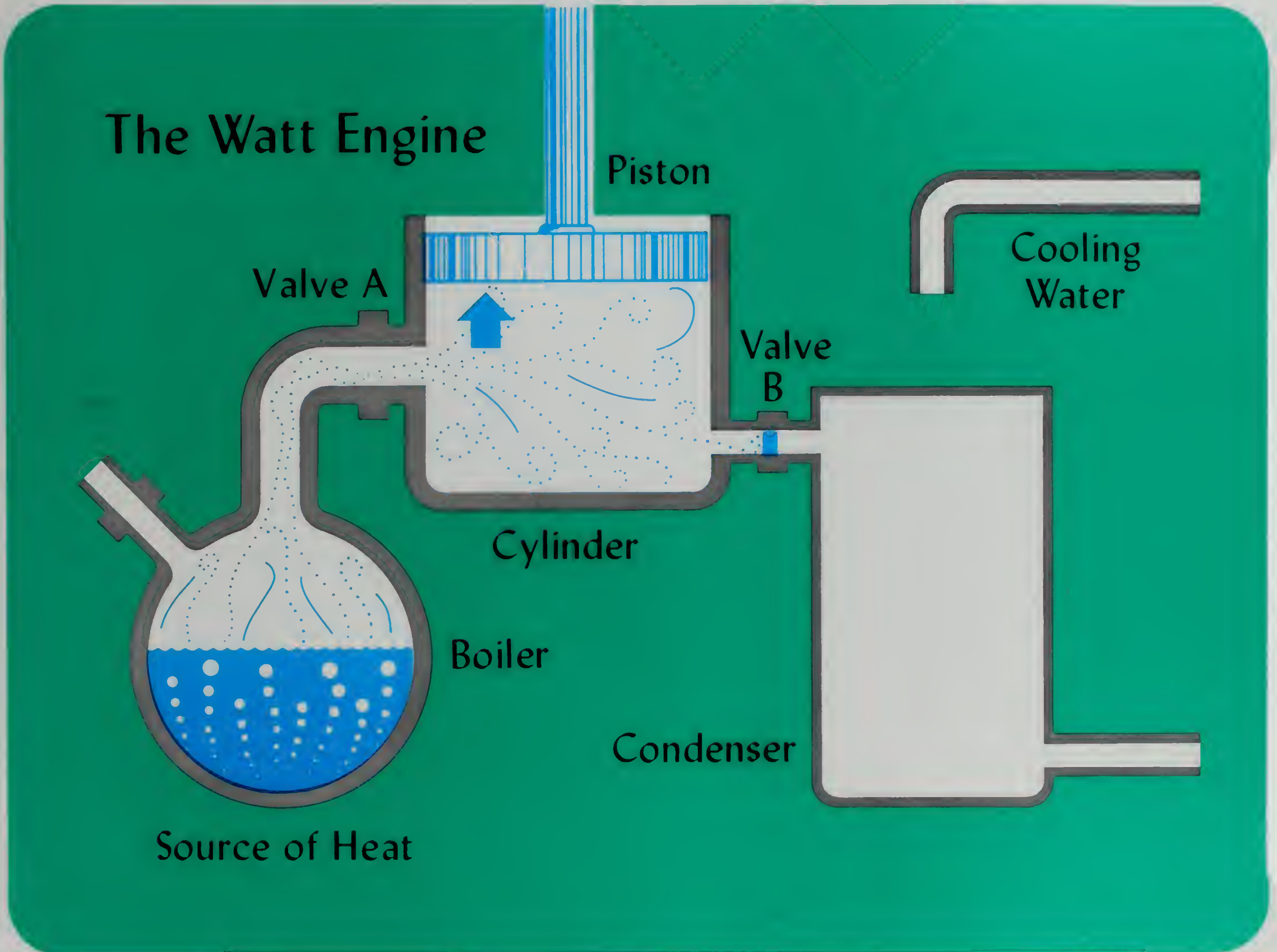
Overlay B Shows the piston in the steam-expansion phase with the steam valve open and the condenser valves off. Remove this overlay and introduce Overlay C.

Overlay C Shows the piston in the condensation phase of the cycle. The piston has fallen as the open condenser valve allows steam to condense in the outer chamber.

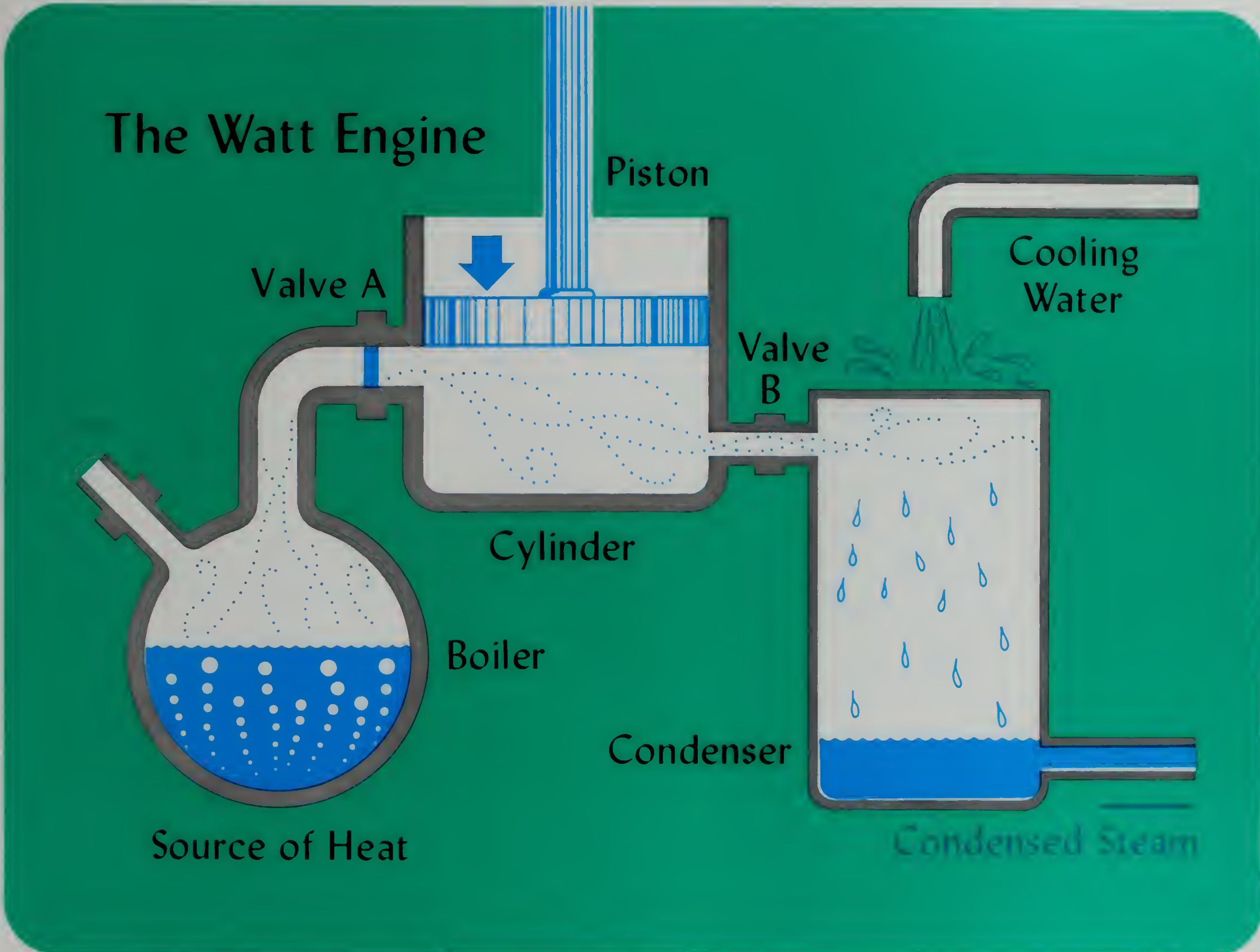
A

The Watt Engine




The Watt Engine
Piston
Valve A
Cooling Water
Valve B
Cylinder
Boiler
Condenser
Source of Heat

A
B


The Watt Engine
Piston
Valve A
Valve B
Cooling Water
Cylinder
Boiler
Condenser
Source of Heat
Condensed Steam

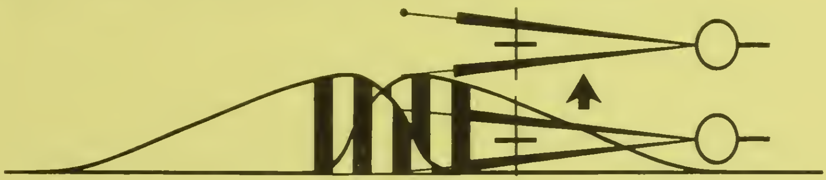
T25

T-25 Superposition

This transparency is intended to expedite the presentation of the principle of superposition. Sequences of traveling pulses on the same side and on opposite sides of the equilibrium line are shown. Amplitudes can be conveniently added with the aid of a mechanical drawing dividers and a wax pencil.

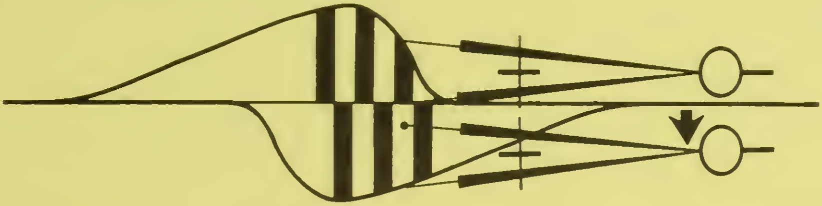
Overlay A Shows a pulse moving to the right at four successive time intervals. The vertical bars provide convenient mark-off points for the algebraic summations of the amplitudes.

Overlay B Shows a pulse moving to the left. Sum up the two pulses by adding one amplitude to the other (see diagram). When you have generated a number of points with this method introduce Overlay C to illustrate the completed superposed wave.



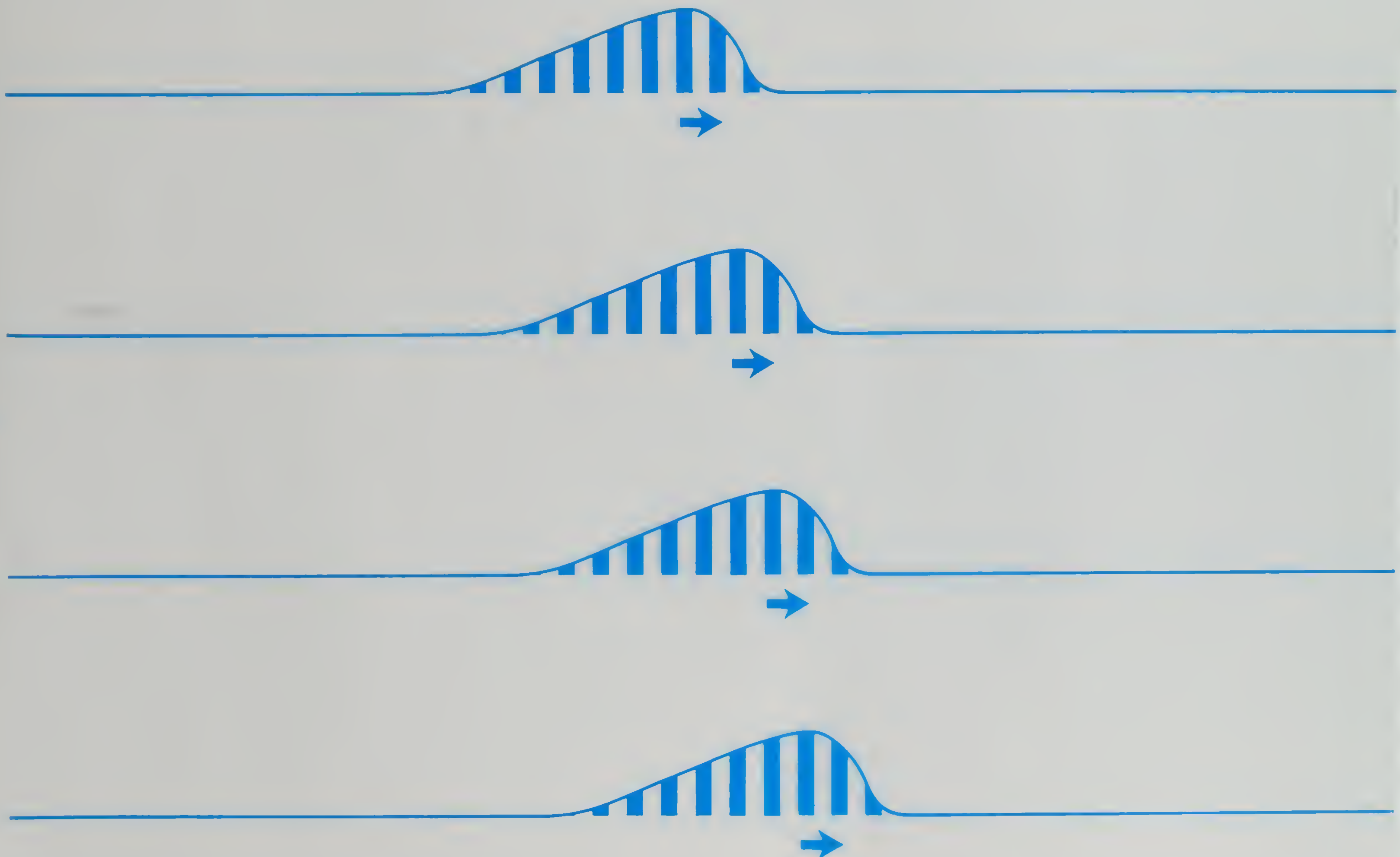
Overlay C Shows the complete resultant wave forms. Remove Overlays B and C and introduce Overlay D.

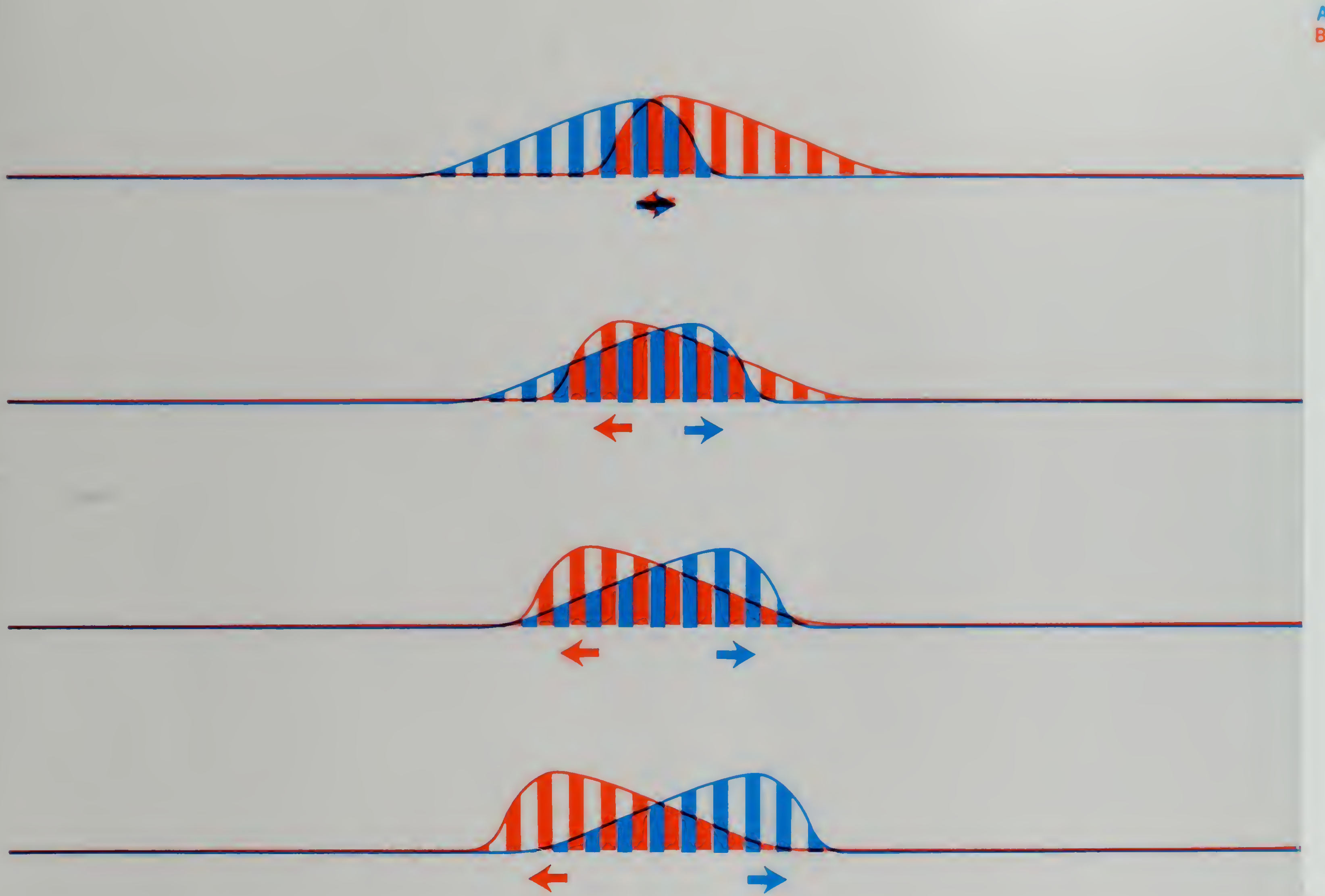
Overlay D Shows a pulse moving to the left on the reverse side of the equilibrium line. Now with the aid of the dividers **algebraically** add the two pulses by subtracting the smaller amplitude from the larger (see diagram).

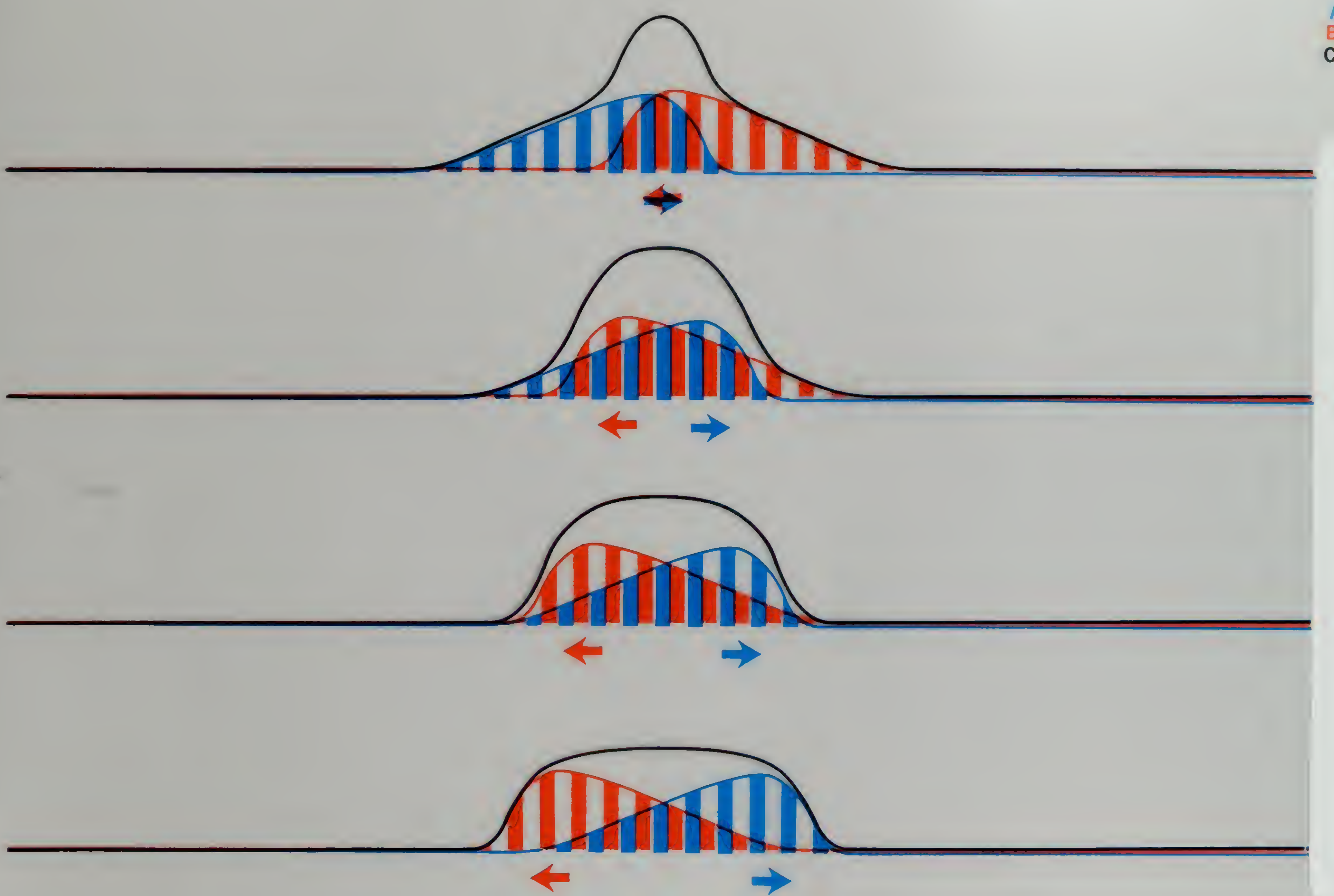


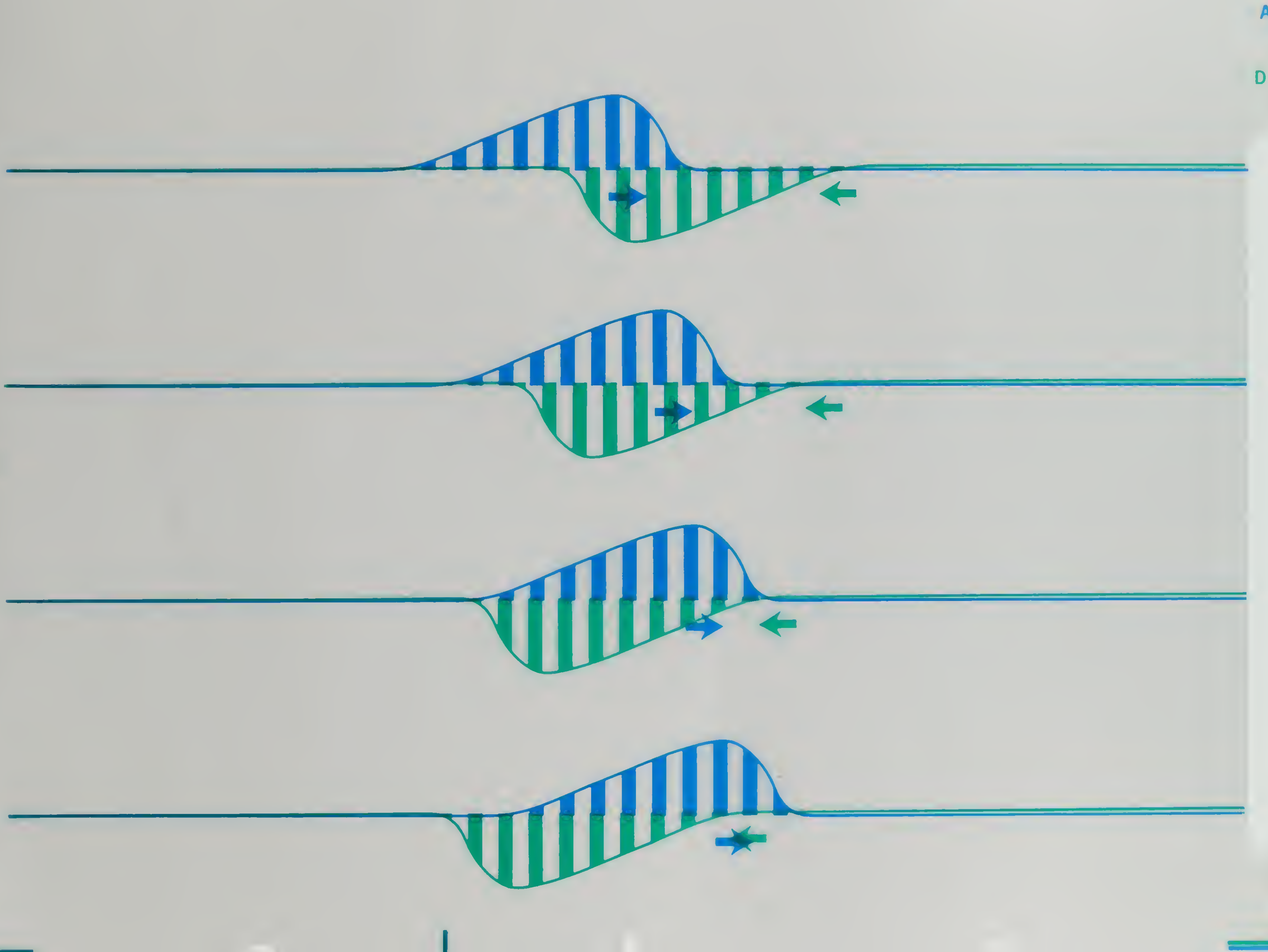
Overlay E Shows the complete resultant wave forms. Notice how the approaching pulses interact with each other as they "pass through" each other.

A




A
B

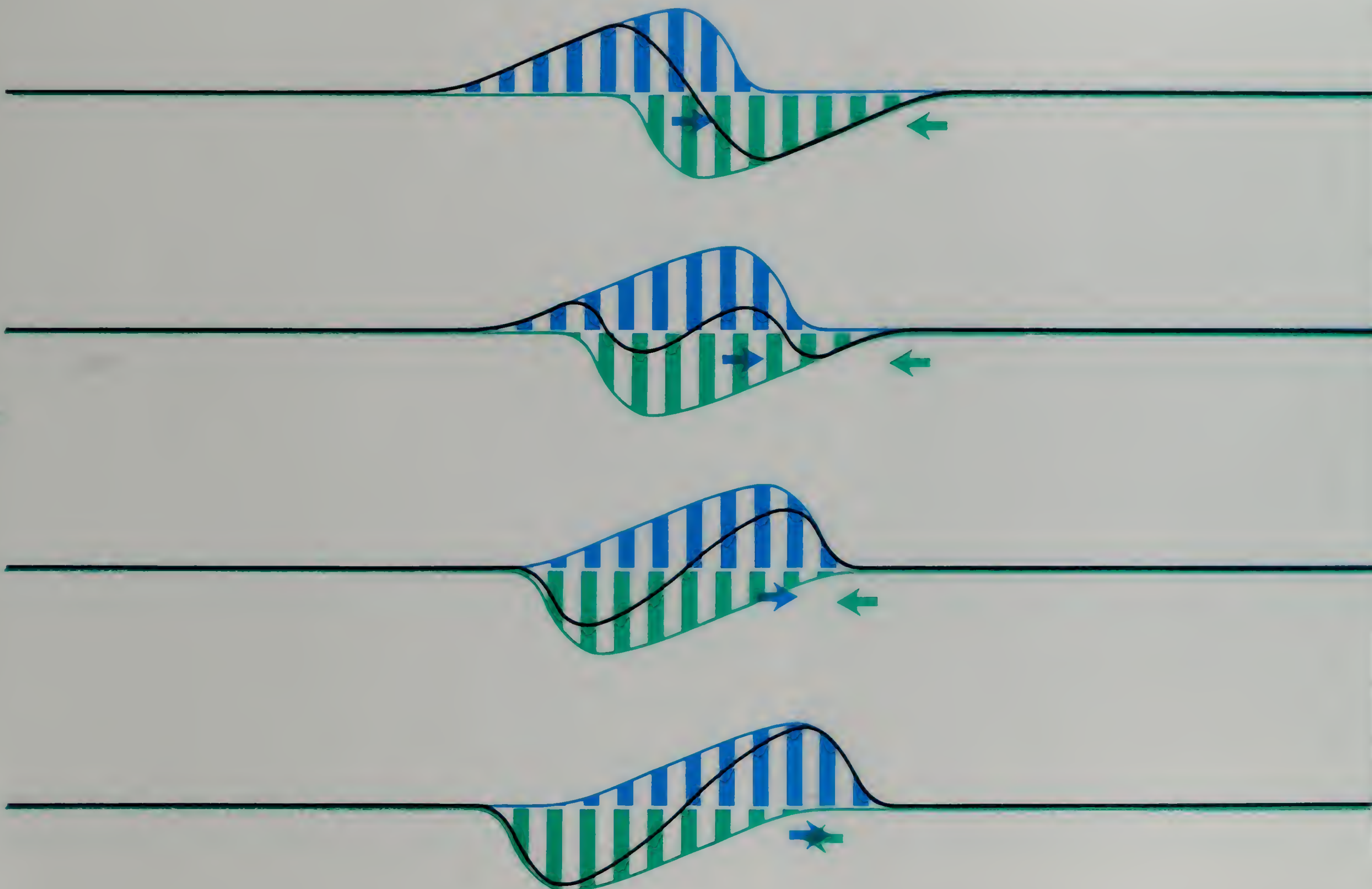

A
B
C



T-25

A

D
E



T26

T-26 Square Wave Analysis

You may employ this transparency to illustrate the effectiveness of the superposition principle in analyzing a complex wave form into a series of simpler component waves. The graphic procedure parallels a Fourier analysis. Additionally, the various wave forms will afford ample practice work for students in applying the superposition principle. (The formation of a square wave is important in all pulsing radar transmitters.)

Overlay A Shows a grid with a heavy central line from which all amplitude measurements are determined.

Overlay B Shows a wave which approximates a square wave. You may suggest the possibility of constructing this complex wave by superposing a number of simpler waves and proceed to show how it is done. (The formation of a square wave is important in all pulsing radar transmitters.)

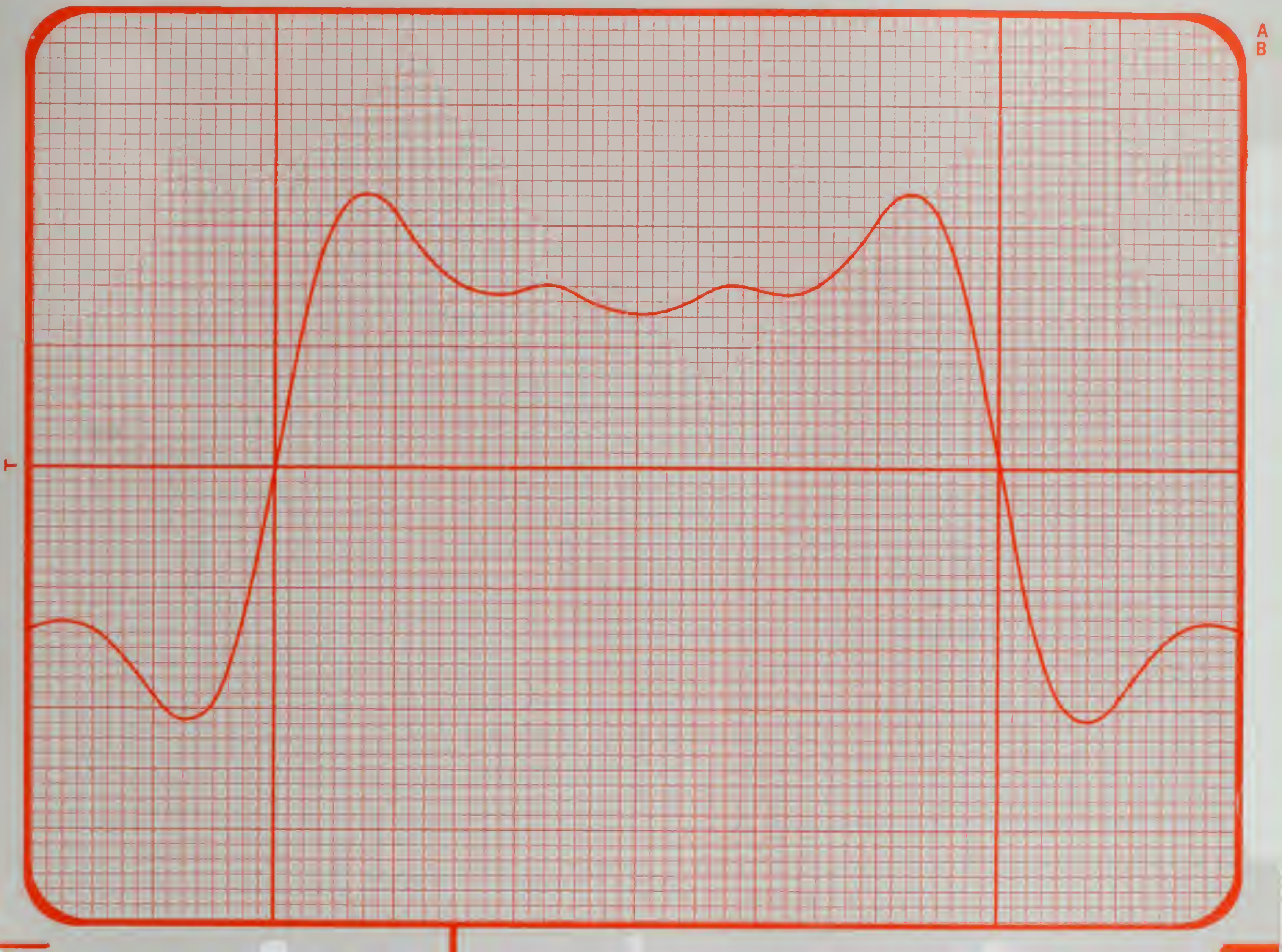
Overlay C Shows a component wave with a wavelength equal to that of the square wave but with some regions of excess and defect which require smoothing out by the addition of more components.

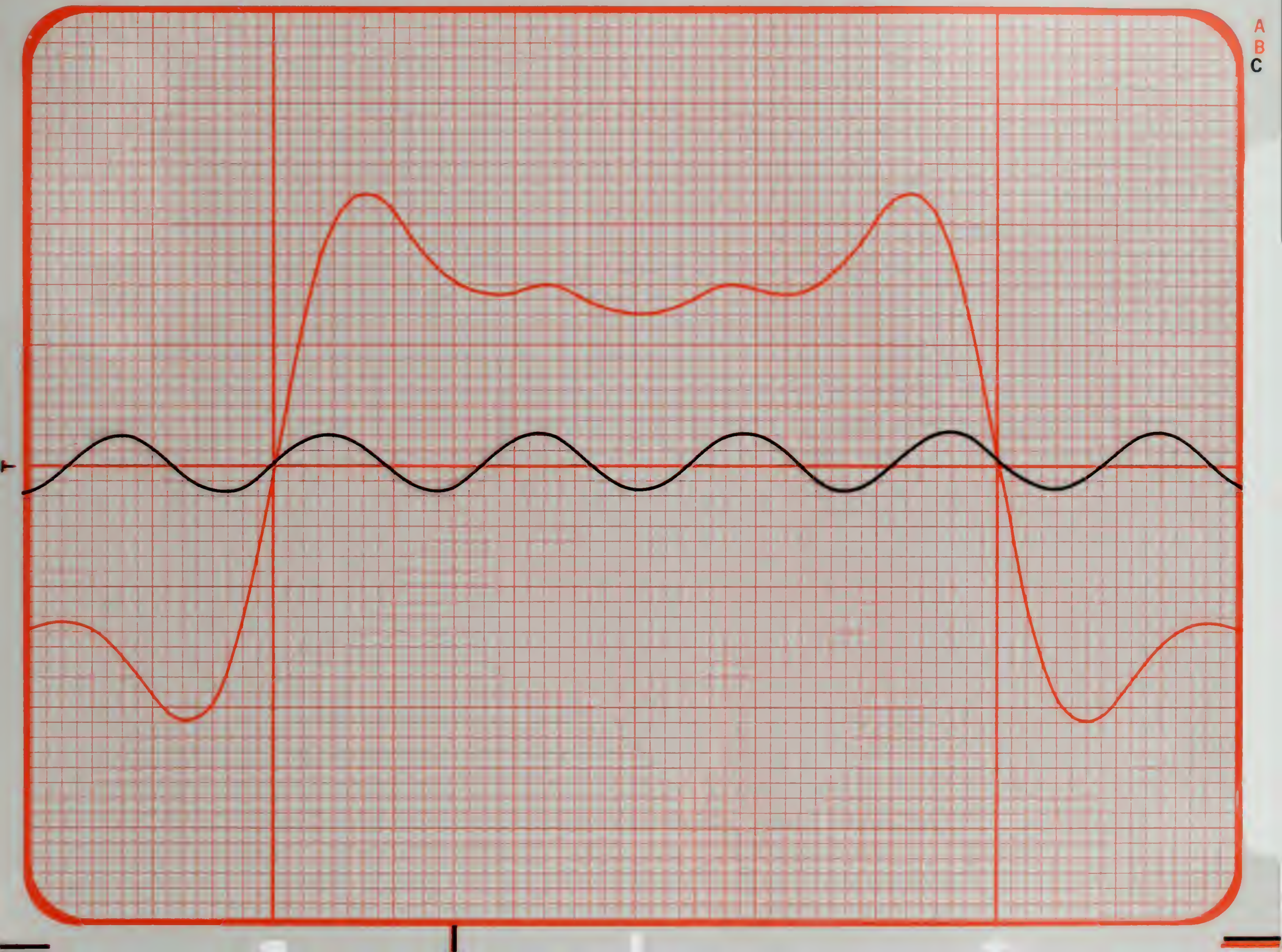
Overlay D Shows the next component with a wavelength one-third the main component. Remove Overlay B and proceed to sum up the two waves of Overlays C and D as indicated in T23. Draw in the resultant wave form. The residual irregularities can be largely removed with additional components of wavelengths 1/5, 1/7, 1/9 . . . times that of the original.

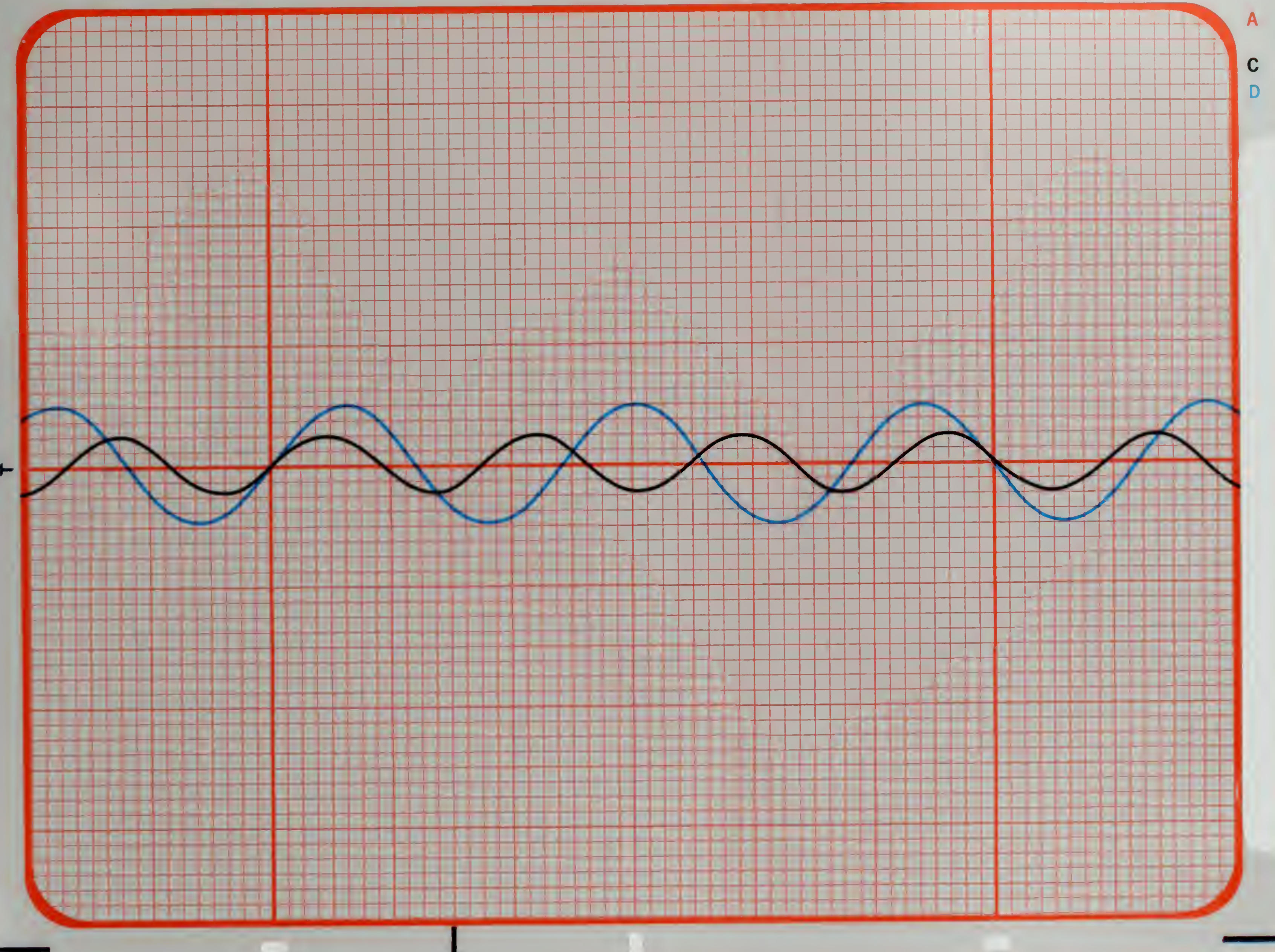
Overlay E Shows a component wave with a wavelength 1/5 the original. Remove Overlay C and superpose the resultant wave of Overlays C and D with the wave on Overlay E.

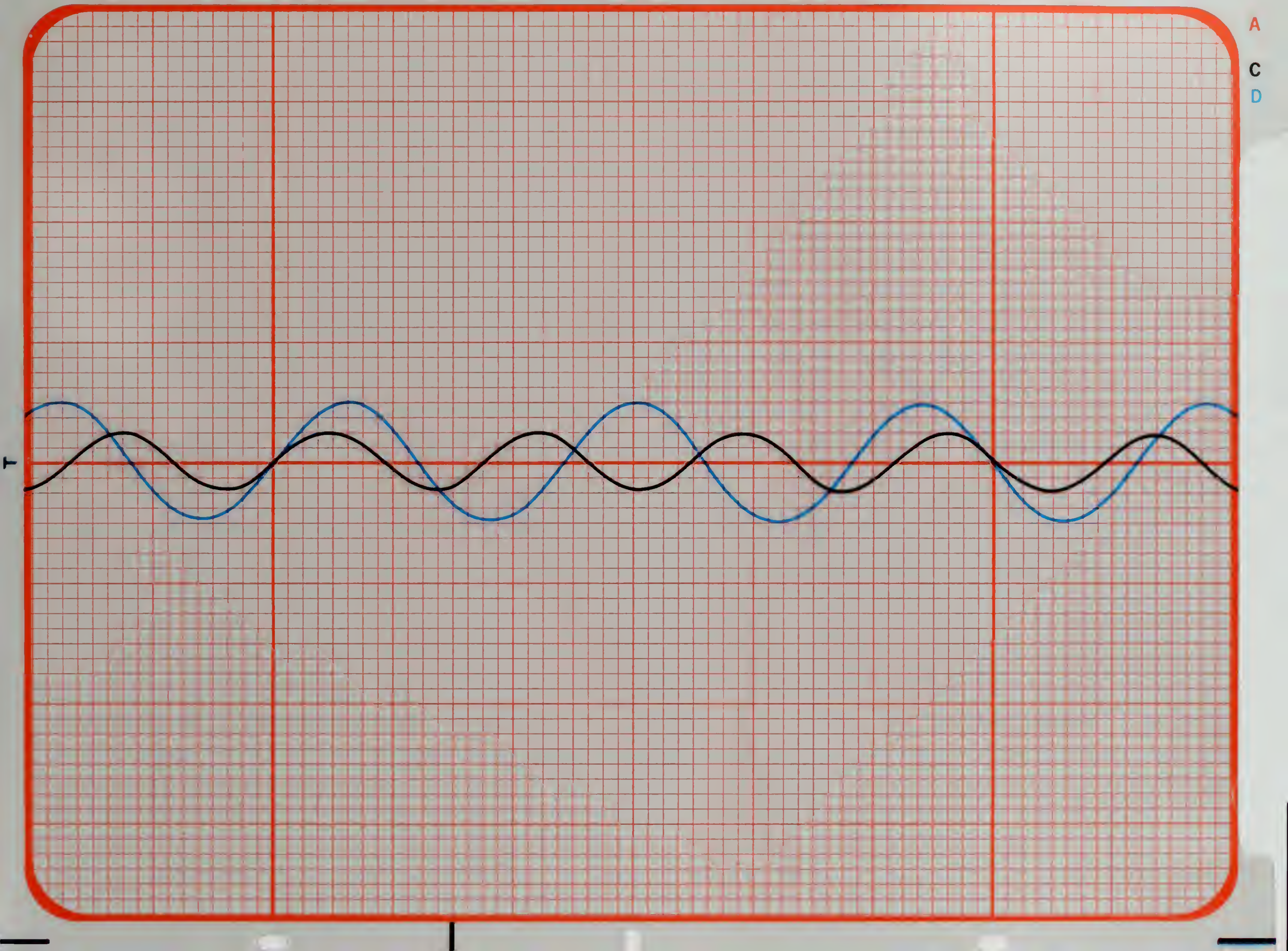
Overlay F Shows a component wave with a wavelength 1/7 the original. Remove Overlay D and superpose wave F with the resultant wave appearing on Overlay E. The final wave should approximate the original square wave. Return Overlay B to verify this.

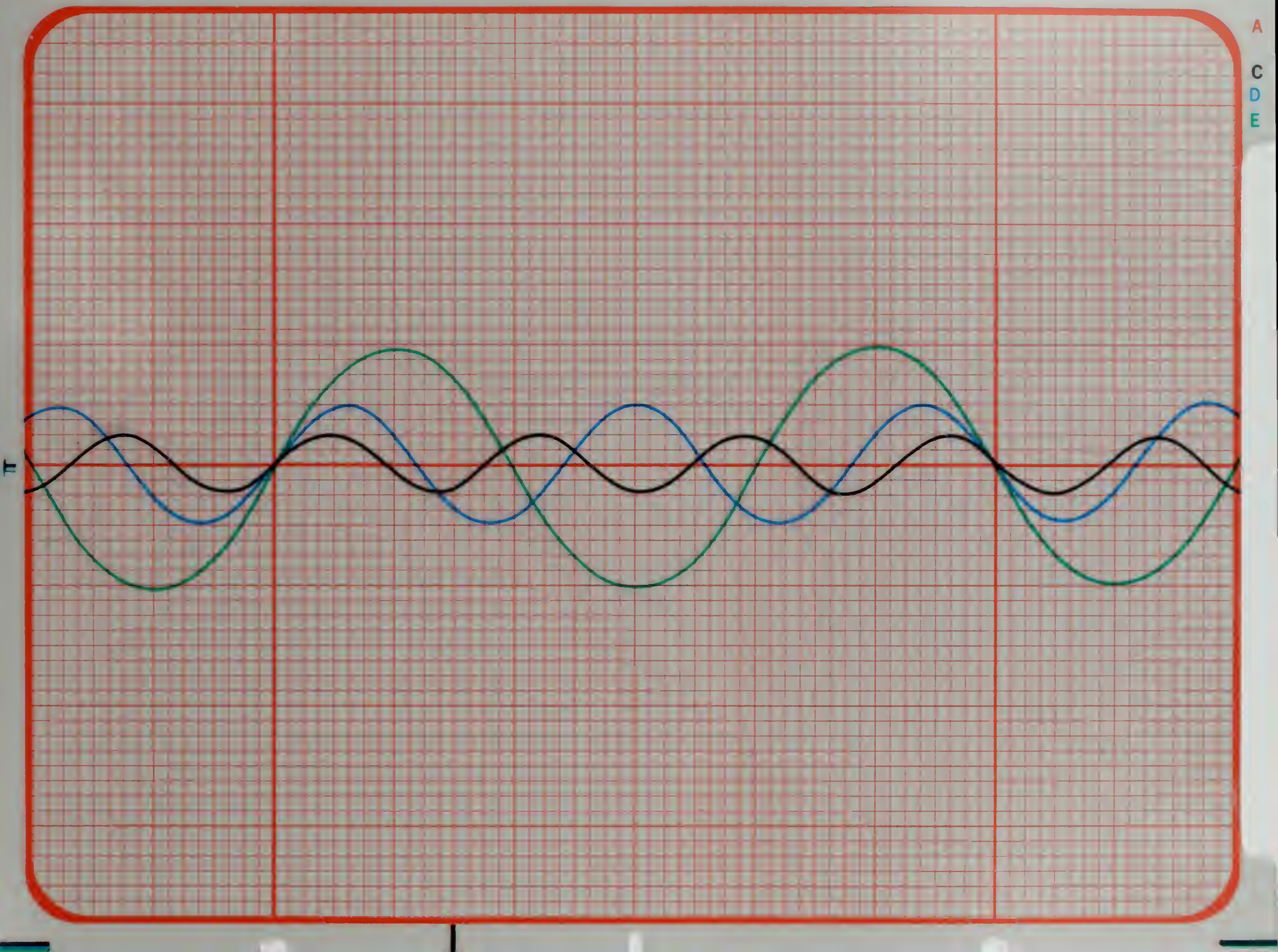
A


A
B
T

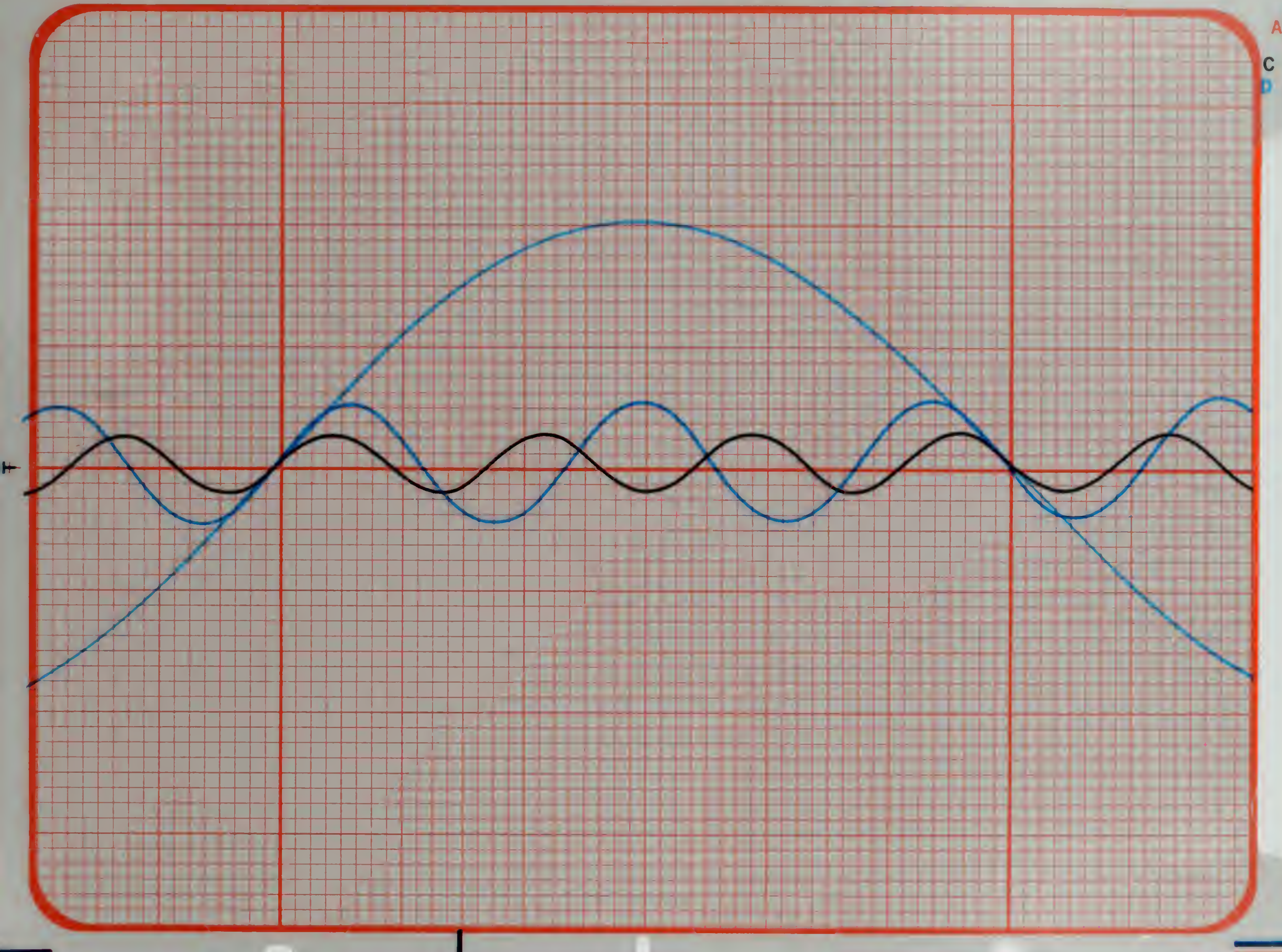

A
B
C


A
C
D
T


A
C
D
T


π
A
C
D
E

T-26



T-28 Two-Slit Interference

T28

This transparency uses the moiré pattern technique to simulate the regions of constructive and destructive interference as produced in a two-source two dimensional interference pattern. A sliding overlay shows the dependence of the nodal line pattern upon the source separation.

Overlay A Shows circular waves emanating from a single slit or from a circular wave source.

Overlay B Shows another set of circular waves emanating from another slit or circular wave source. Match this overlay carefully with the dot on Overlay A. A distinct nodal line pattern will be seen where these two sources overlap.

To illustrate the dependence of this pattern on the separation of the sources, carefully move this loose overlay above or below the point on Overlay A. Notice how the pattern changes as the sources are moved apart.

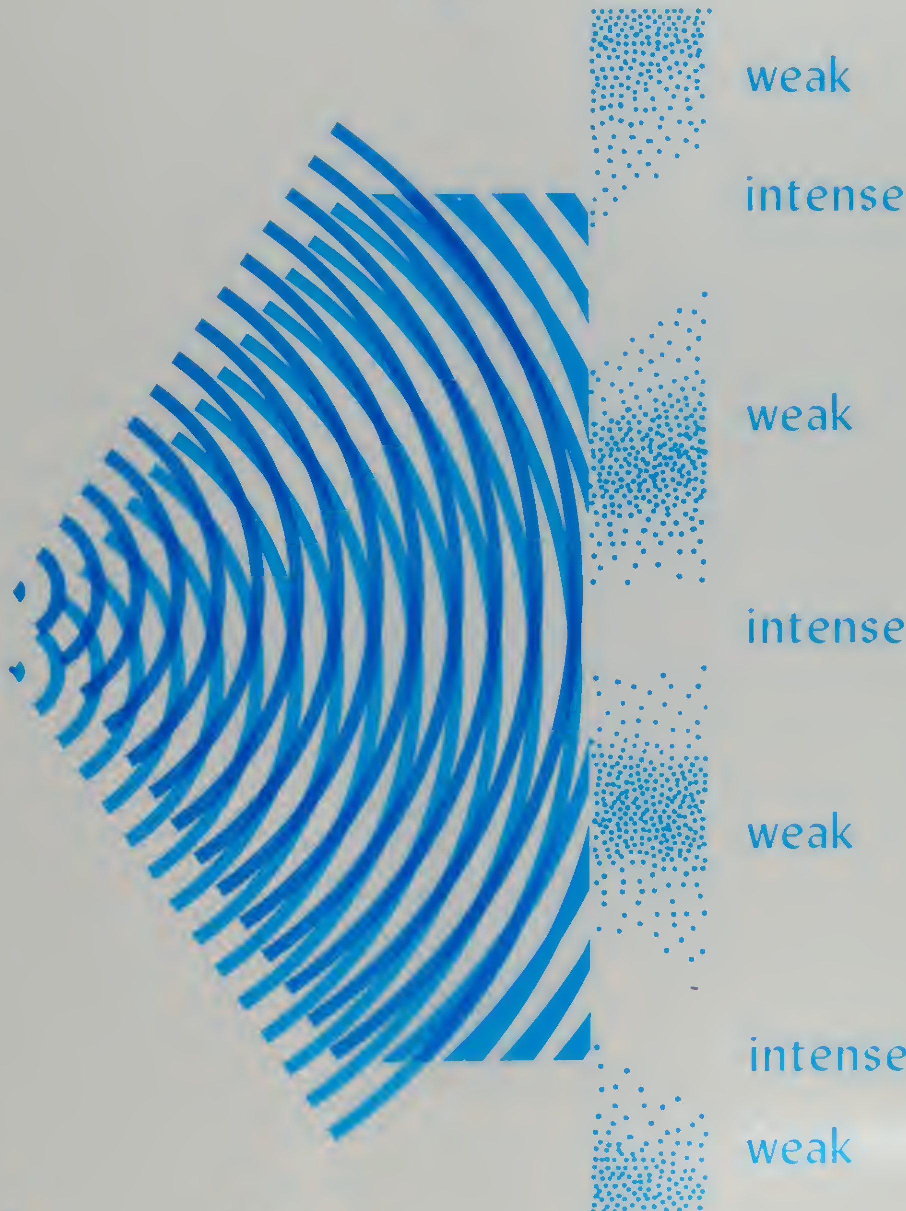
Overlay C Shows the fringe pattern which might be observed at a distance from the sources in any number of wave phenomena (light, sound, microwaves, etc.). Be sure Overlay B is lined up with the dot on Overlay A.

A

A
B

T

A
B
C



T

T-29 Interference Pattern Analysis

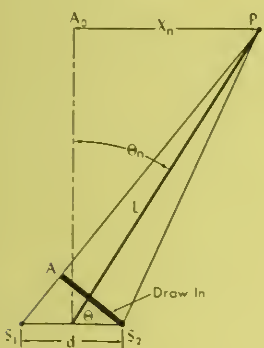
This transparency will be useful in analyzing the interference pattern produced by a double slit barrier. You may also employ it to derive the wavelength equation.

Overlay A Shows a set of crests (lines) and troughs (space between lines) emanating from source S.

Overlay B Shows a similar set of waves emanating from source S_2. You may discuss the formation of constructive and destructive interference points by indicating the crest-crest, trough-trough and crest-trough overlaps. Place a series of points with a wax pencil directly on the overlay to indicate interference points. Then introduce Overlay C to show the complete pattern.

Overlay C Shows the complete pattern with nodal and anti-nodal lines. Remove Overlays A and B and introduce Overlay D.

Overlay D Shows the geometry needed to derive the wavelength equation. First choose a point P on a anti-nodal line and show that the relationship PS_1-$PS_2 = n\lambda$ holds, where n is the number of the anti-nodal line.



Now draw a line from S_2 to A such that $PS_2 = PA$ (see diagram). Then $PS_1 - PS_2 = AS_1$. Assume that P is far enough so that PS_1 and PS_2 are nearly parallel and that angle S_1AS_2 is a right angle. Then Sin $\theta = AS_1/d$ (Identify angle AS_2S_1 as θ).

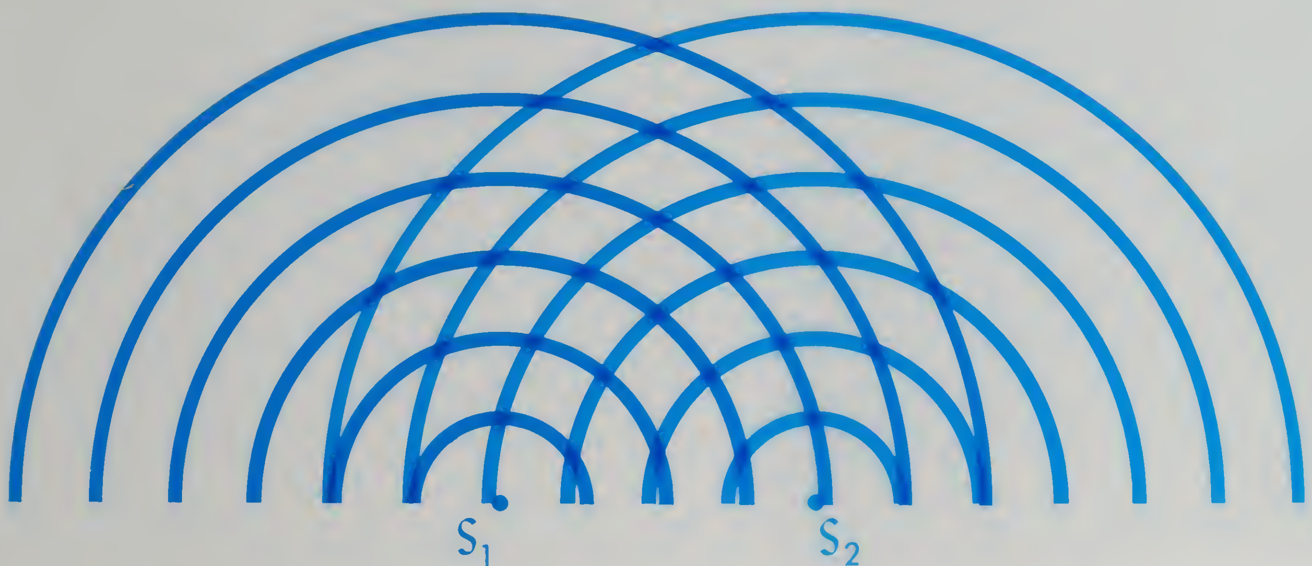
Since $AS_1 = PS_1 - PS_2$ then $PS_1 - PS_2 = d \sin\theta$. When P is on the nth anti-nodal line $PS_1 - PS_2 = n\lambda$, therefore $n\lambda = d \sin\theta$ as long as P is far from S_1 and S_2.

Now show that $\theta = \theta_n$ by observing that line L and PS_1 are practically parallel to each other and both are perpendicular to AS_2. The center line A_0 is perpendicular to d and $\theta_n = \theta$. Then $\sin\theta_n = X_n/L$ or

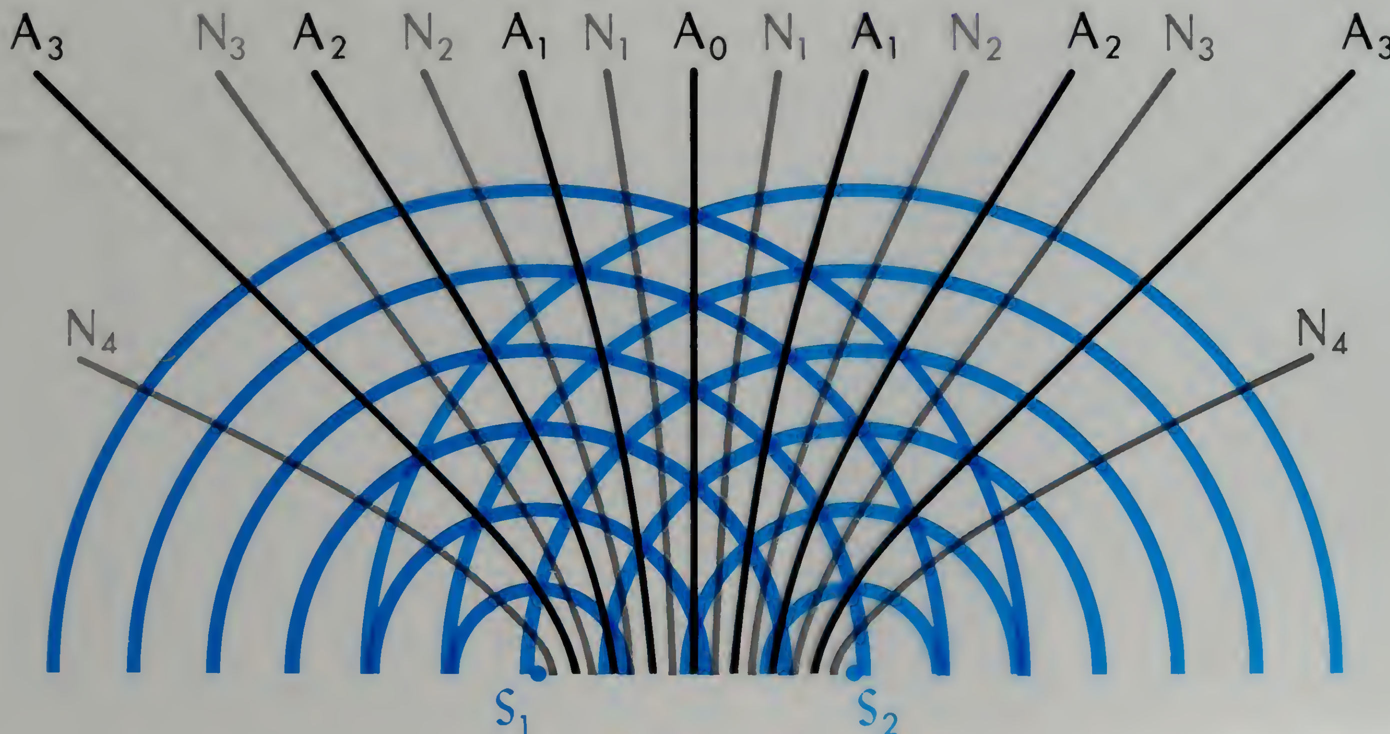
$$\lambda = \frac{d(X_n/L)}{n}$$

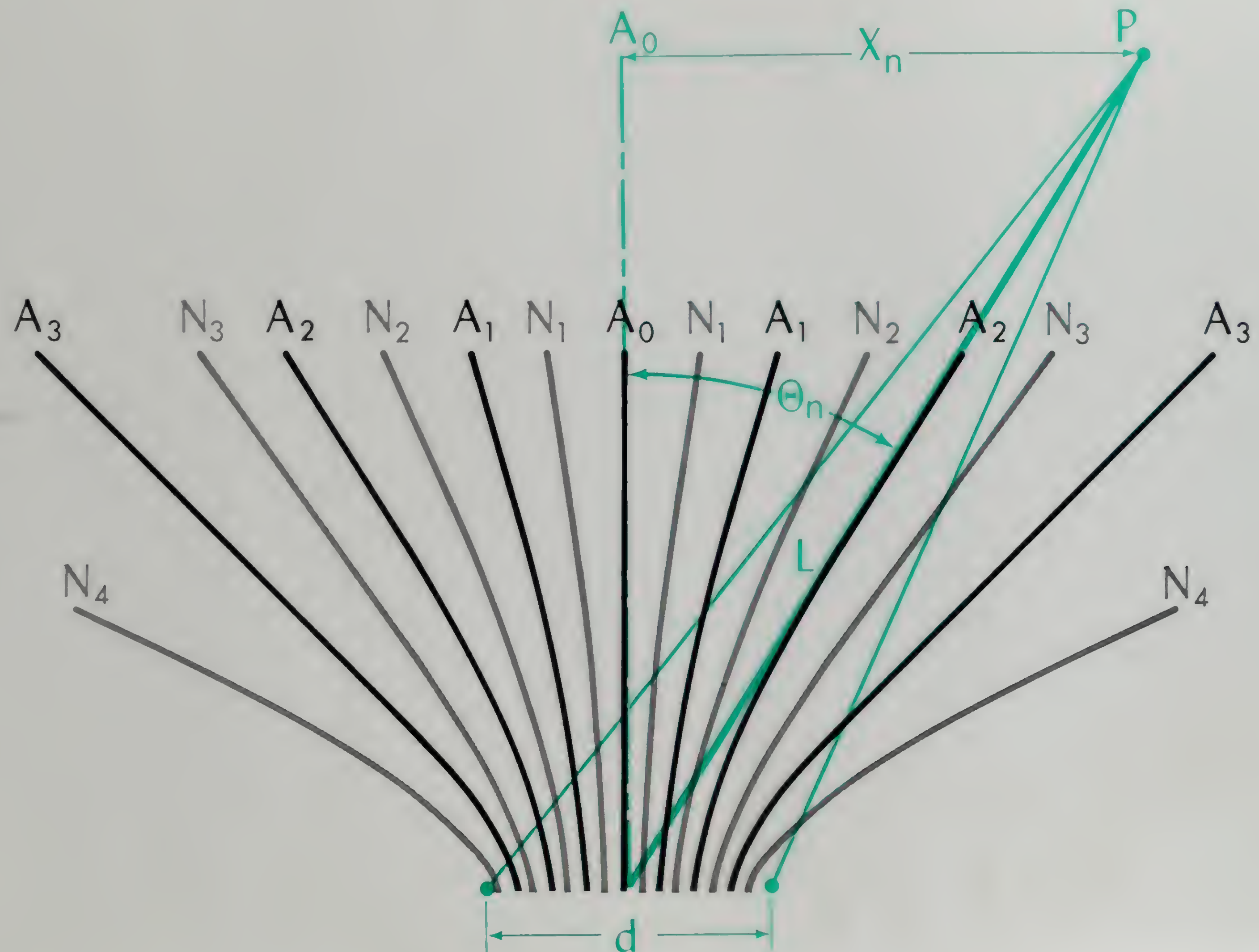
A

A
B



A
B
C




A0
Xn
P
A3
N3
A2
N2
A1
N1
A0
N1
A1
N2
A2
N3
A3
θn
L
N4
N4
d