WATSON

The Project Physics Course

Unit 2 Transparencies

Motion in the Heavens

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Transparencies

UNIT 2

Motion in the Heavens

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Project Physics

Overhead Projection Transparencies

Unit 2

Stellar Motion and Celestial Coordinates

Stellar Motion

If at all possible, students should observe stellar motion directly before trying to analyze it. After they have made such observations, or have been made aware of the motions by means of photographs, the ancient conceptual scheme of the "two-sphere universe" can serve as a model to explain stellar motion.

In order to avoid miniscule dimensions for the earth, the diagrams are not drawn to scale. As a result, the horizon plane is drawn through the center of the celestial sphere rather than tangent to the place of observation.

Overlay A The earth is shown at the center of the universe with the celestial sphere turning to the left on its celestial poles.

Overlay B The three horizontal circles represent the paths of selected stars which are attached to the sphere at it rotates daily. These circles indicate the diurnal motion of the stars as seen by an observer in the mid-northern latitudes. From this location, some stars will appear to circle about the Pole Star, some will seem to rise in the east and set in the west, while others will never be seen. Remove overlay B before introducing Overlay C.

Overlay C Stellar motion as seen by an observer at the north pole is illustrated. All stars seem to revolve about the Pole Star. Remove Overlay C before introducing Overlay D.

Overlay D Stellar motion as seen by an observer at the earth's equator. Each evening, all stars seem to rise in the east and set in the west.

Celestial Coordinates

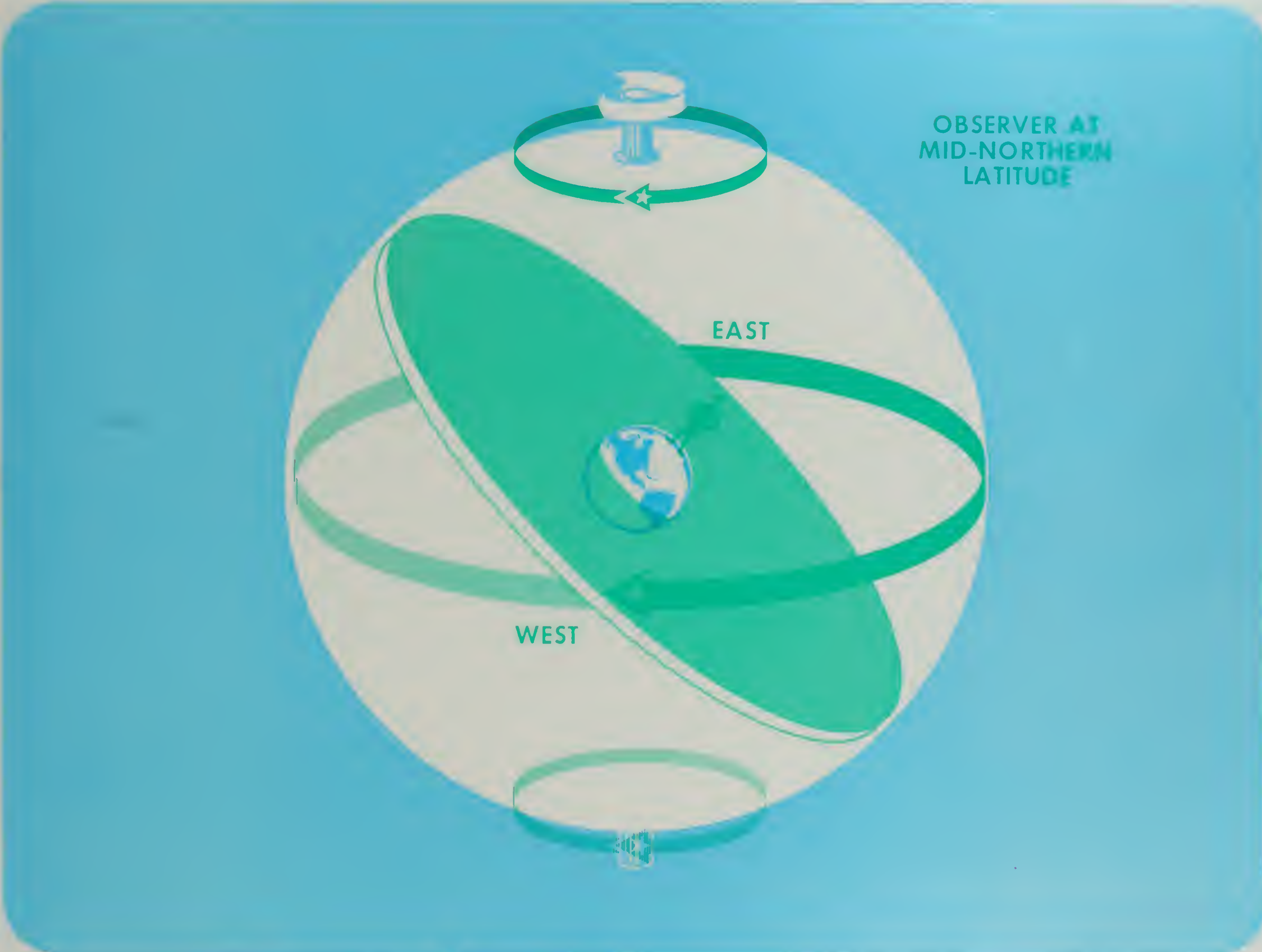
This transparency is useful in explaining two of the systems of coordinates used to locate stars and planets.

Use A for the first overlay, then add E.

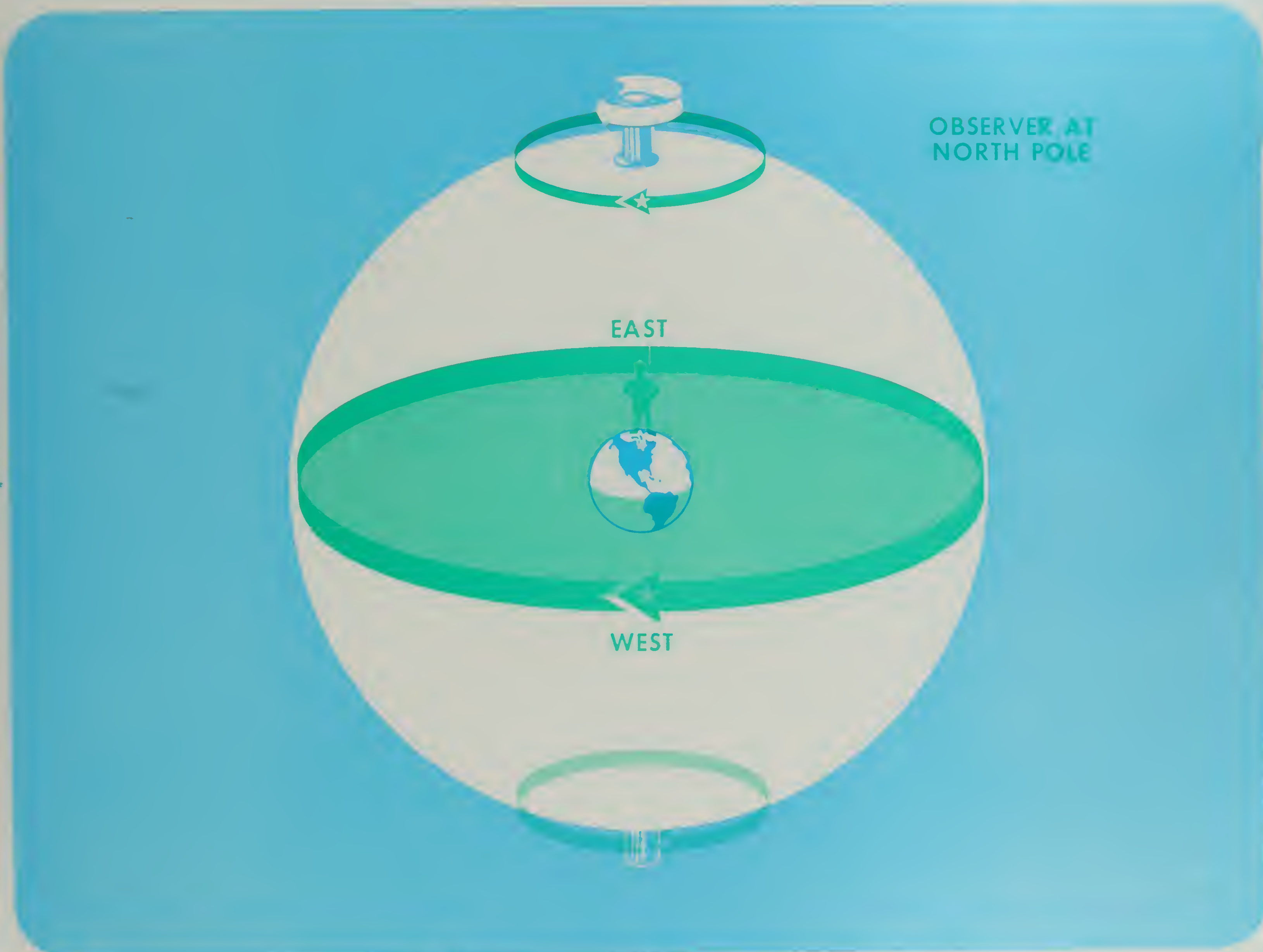
Overlay E This scheme for specifying the locations of stars imagines a celestial sphere whose poles pass through the earth's poles. Hour circles begin at the Vernal Equinox and proceed to the right. (The Vernal Equinox is described in T14). The *Right Ascension* of a star is measured eastward along the celestial equator in hours and minutes. The *Declination* of a star is measured in degrees north or south of the celestial equator (a projection of the earth's equator) along the star's hour circle. Remove Overlay E before introducing F.

Overlay F Another scheme for specifying the locations of stars and planets in or near the zodiac is based on the ecliptic, the sun's annual path across the sky. Celestial longitude begins at the Vernal Equinox and is measured eastward to 360° along the *Ecliptic*. Celestial latitude is measured in degrees north and south with 0° at the ecliptic.

A

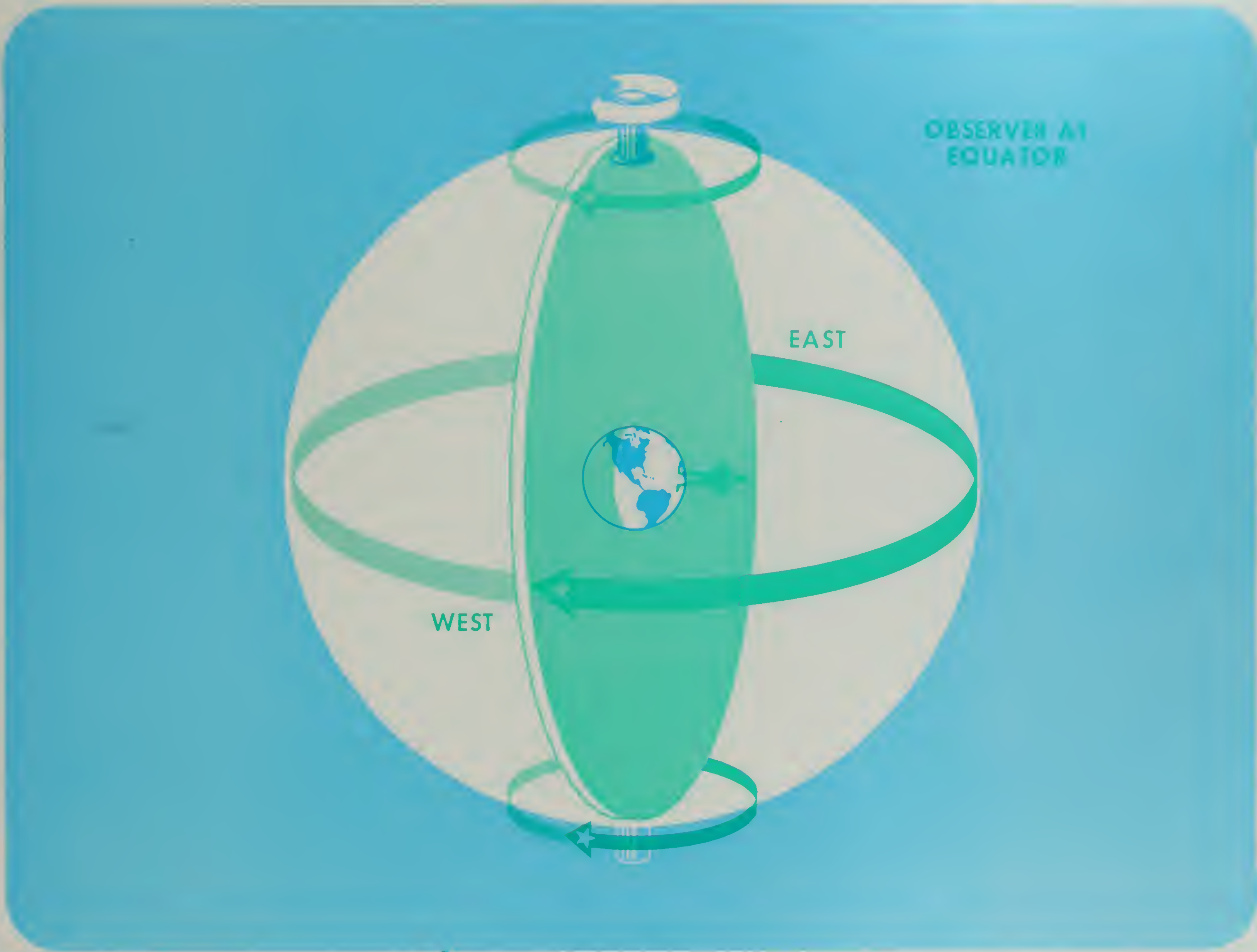


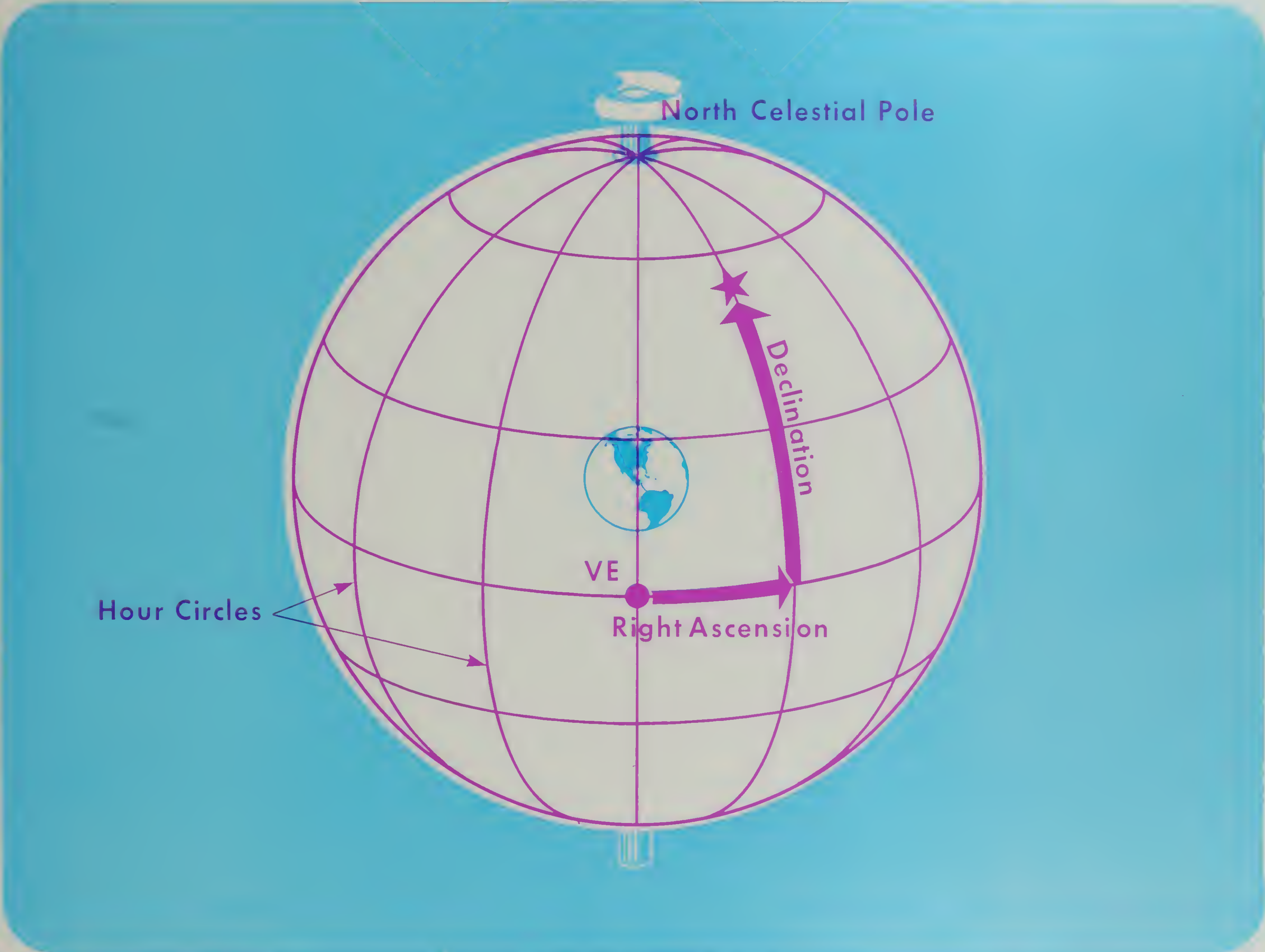
A
B


OBSERVER AT
NORTH POLE
EAST
WEST

A

D




North Celestial Pole
Declination
VE
Hour Circles
Right Ascension


Pole of the Ecliptic
Celestial Latitude
VE
Celestial Longitude

Celestial Sphere

Celestial Sphere

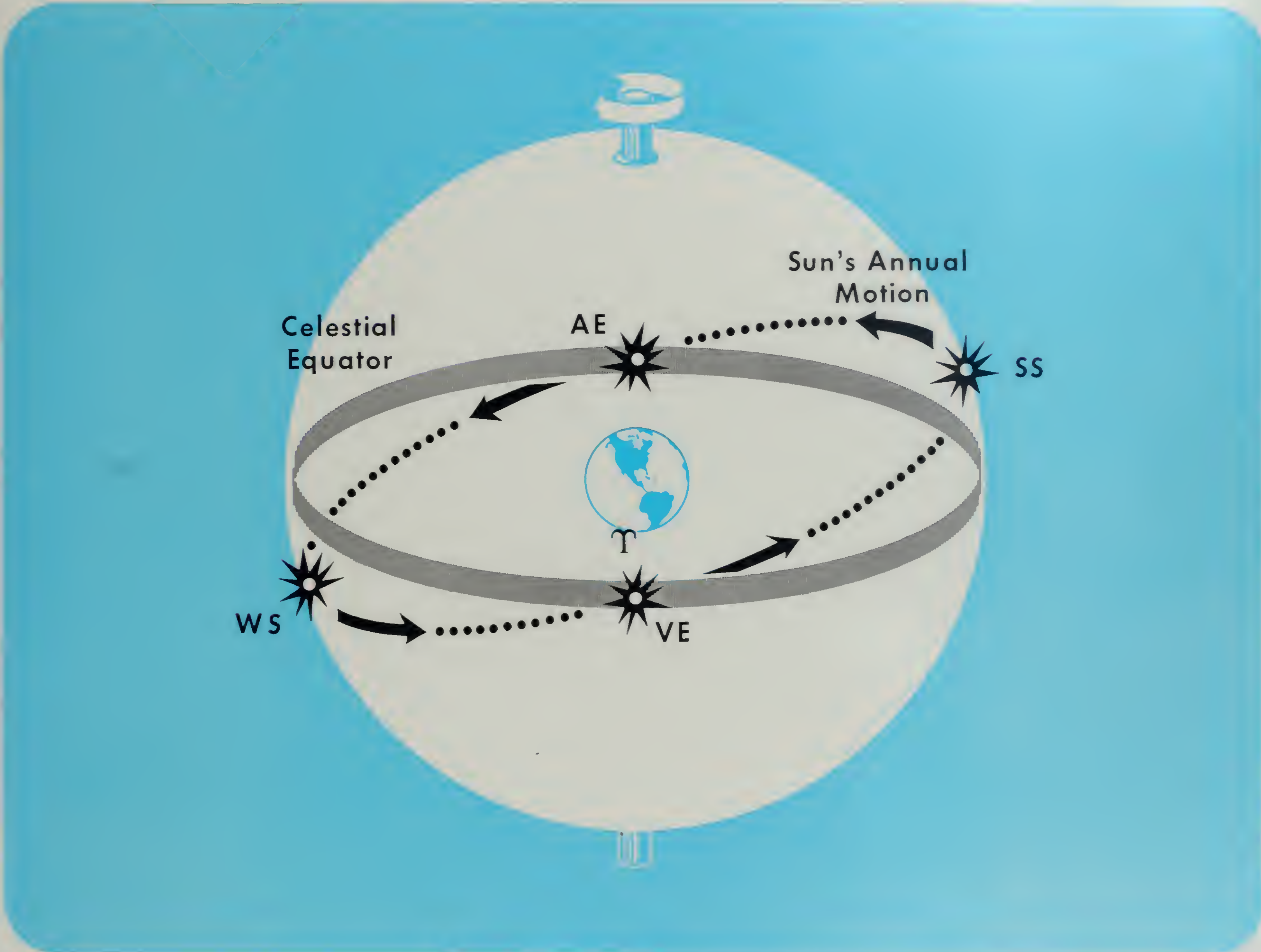
This transparency will be useful in visualizing some of the important features explained by the celestial sphere.

Use overlay T13-A for the first overlay, then add T14-A.

Overlay A The celestial equator is a projection of the earth's equator on the celestial sphere. The sun is shown moving to the right (eastward) along a great circle on the celestial sphere. The daily rotation of the sphere accounts for night and day. The *annual* rotation of another sphere, which carries the sun and has a pole 23½° from the pole of daily rotation, accounts for the sun's annual motion eastward with the seasonal north-south variations. The sun's path across the sky is known as the *ecliptic*. The point of intersection of the ecliptic and the celestial equator as the sun travels from south to north along the ecliptic is called the *Vernal Equinox*. The crossing occurs approximately on March 21. The *Summer Solstice* (shown as *SS*) occurs on about June 21, the *Autumnal Equinox* (*AE*) on about September 22, and the *Winter Solstice* (*WS*) on about December 21.

Overlay B The *Zodiac* is a belt 18° wide which circles the sky and is centered on the ecliptic. The sun, moon, and planets are always located within this belt. The zodiac is divided into twelve constellations called the Signs of the Zodiac.

A



A
B


Leo
Cancer
Virgo
Libra
Scorpius
Gemini
Sagittarius
Taurus
Aries
Pisces
Capricornus
Aquarius

T15

Retrograde Motion

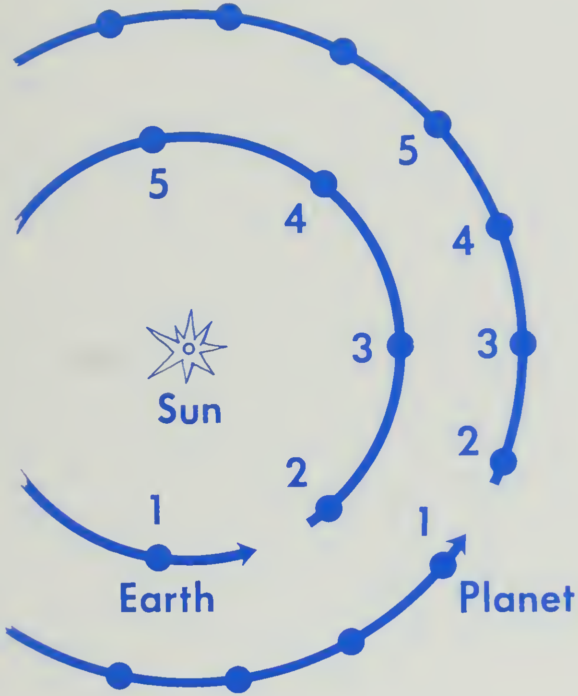
Retrograde Motion

The heliocentric explanation of an outer planet's observed retrograde motion can be demonstrated using this transparency.

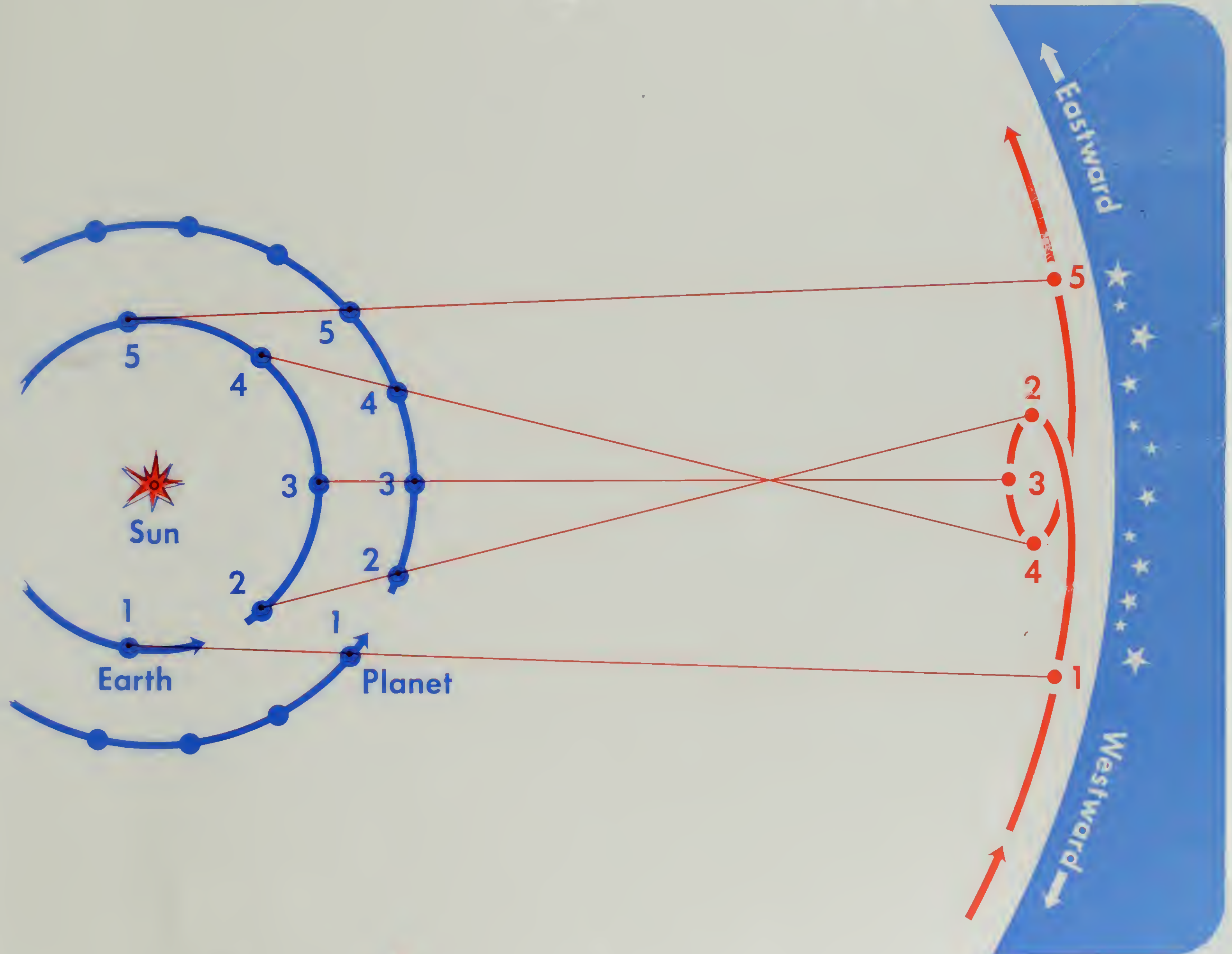
Overlay A — The earth and an outer planet are shown at successive positions along their orbits. The time intervals between the indicated positions are equal. Introduce blank overlay B.

Overlay B — Draw in sight lines directly on this blank overlay. Connect points 1-1, 2-2, . . . , etc., for the earth and planet, and extend the lines to the star field on the right. These lines will show that the planet, as seen from the earth, appears to move westward (retrograde) when it is opposite to the sun. Remove overlay B before introducing overlay C.

Overlay C — This shows the completed operation suggested in B above. The apparent path is marked in to aid discussing retrograde motion.


5
4
3
2
1
5
4
3
2
1
Sun
Earth
Planet


Eastward
Westward


Eastward
Westward
5
2
3
4
1
5
4
3
2
1
Sun
Earth
Planet

T16

Eccentrics and Equants

Eccentrics and Equants

These transparencies can be used to present a rapid review of the geometrical devices of the Ptolemaic geocentric model of the universe. Do not belabor the details but simply point out the usefulness of the various geometric devices. Emphasize the fact that they account for the variations observed in planetary motion, while at the same time they preserve the Platonic scheme of uniform angular motion.

Eccentries

Overlay A — This is a reference circle which will be used for both parts of T16.

Overlay B (Circle) — A planet is depicted moving with uniform angular speed at a constant distance from center **O**. It's path is a perfect circle and therefore an earth observer at **O** would measure equal increments of angular change of position in successive equal time intervals.

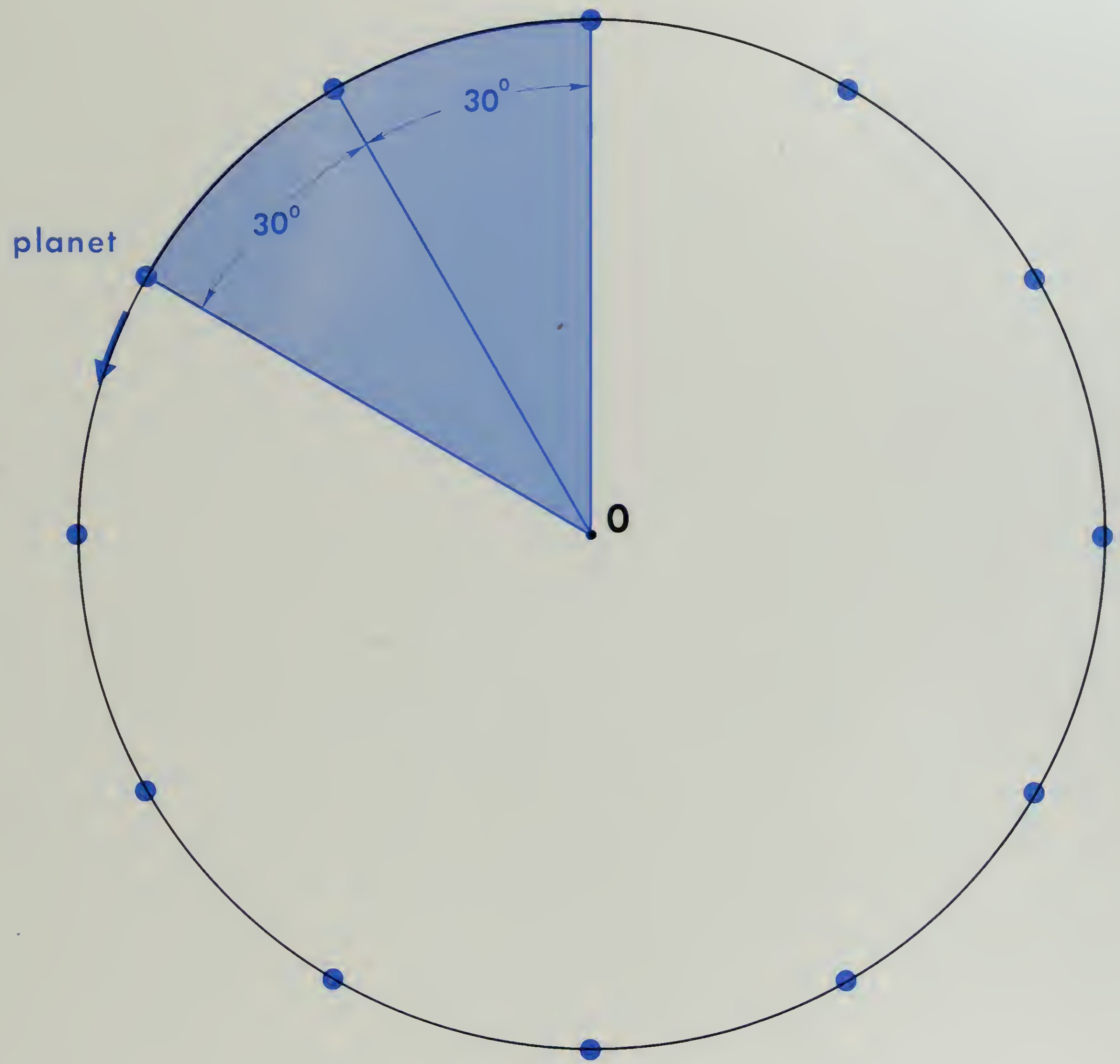
Overlay C (Eccentric) — This shows the earth in an off-center, or eccentric, position. Now the planet does not exhibit uniform speed relative to an observer on earth. Remove overlays B and C before introducing D.

Equants

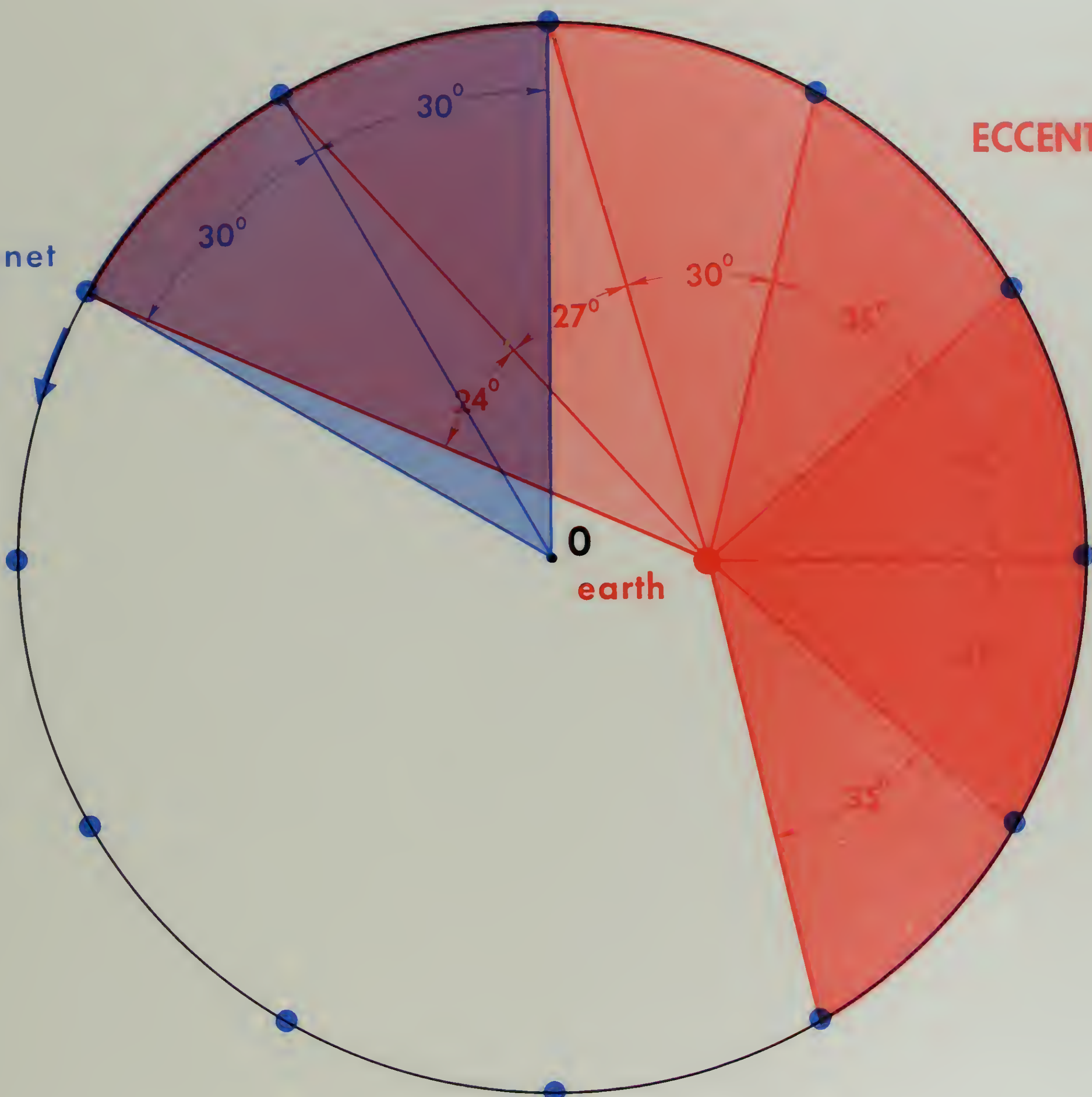
Overlay D (Equant) — The *equant* is another geometric device for preserving uniform circular motion. The planet proceeds with uniform angular motion about an off-center point **C**, while tracing out a perfect circular path of radius R about point **O**.

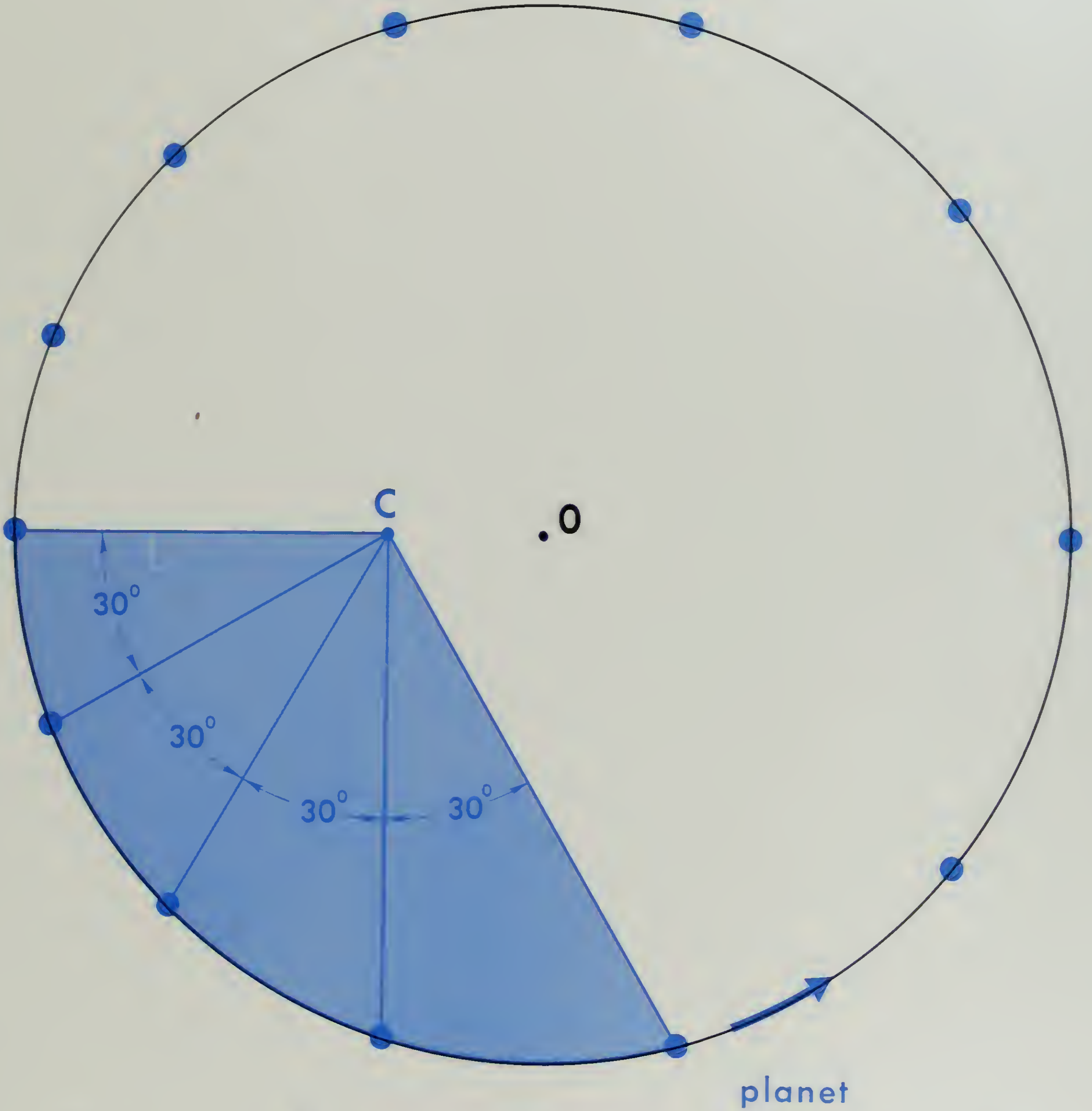
Overlay E — Now the earth is placed off-center in the equant system. Angular displacements measured from the off-centered earth will yield results different from those obtained with the eccentric alone. Thus the equant was used by Ptolemy to explain variations in planetary motion not accounted for by the eccentric.

A
B



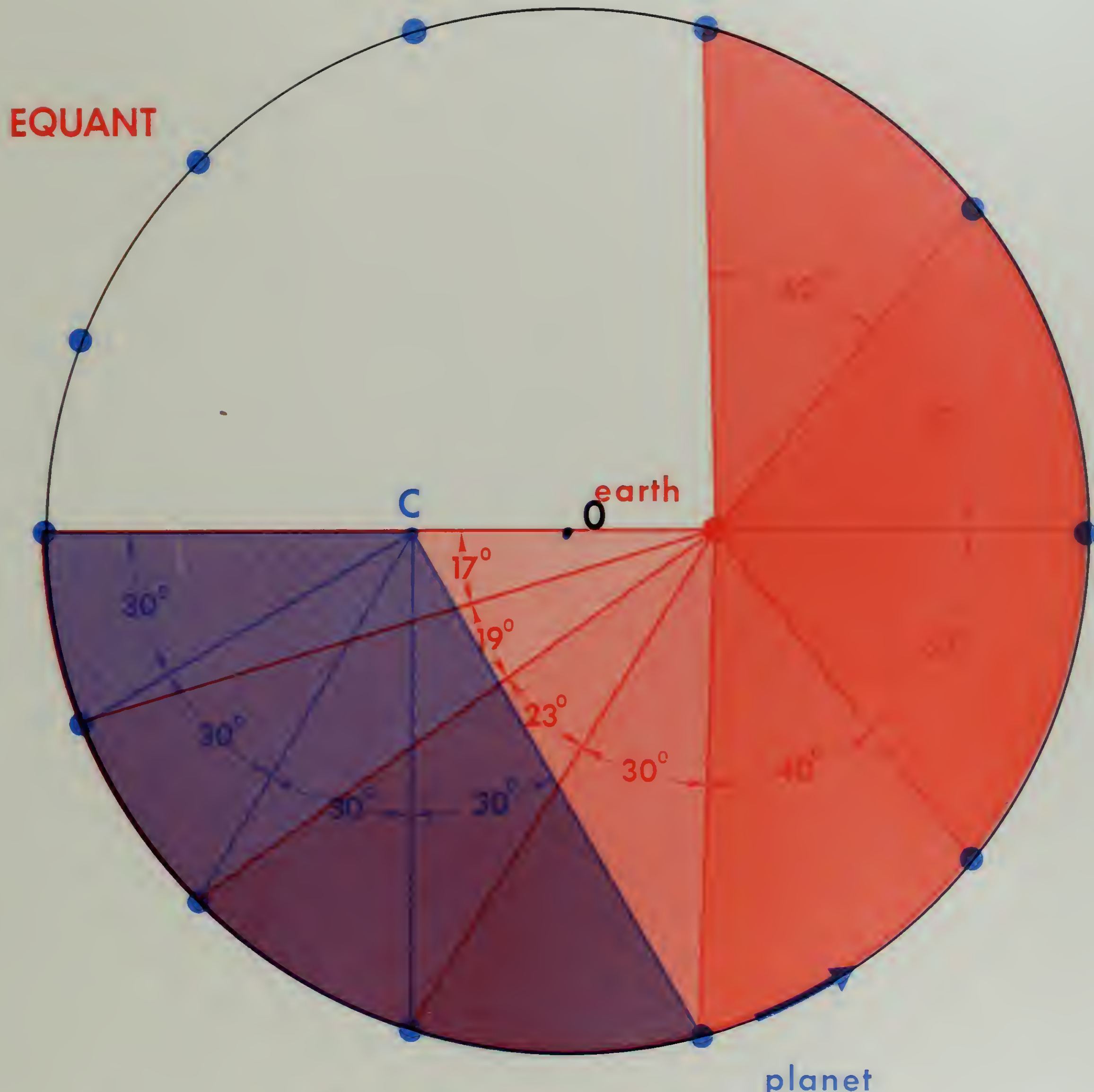
A
B
C




C
.0
30°
30°
30°
30°
planet

A

D
E



Orbit Parameters

T17

Orbit Parameters

This transparency can be used to extend the discussion of Kepler's first two laws and to clarify details of the various celestial experiments of Unit 2.

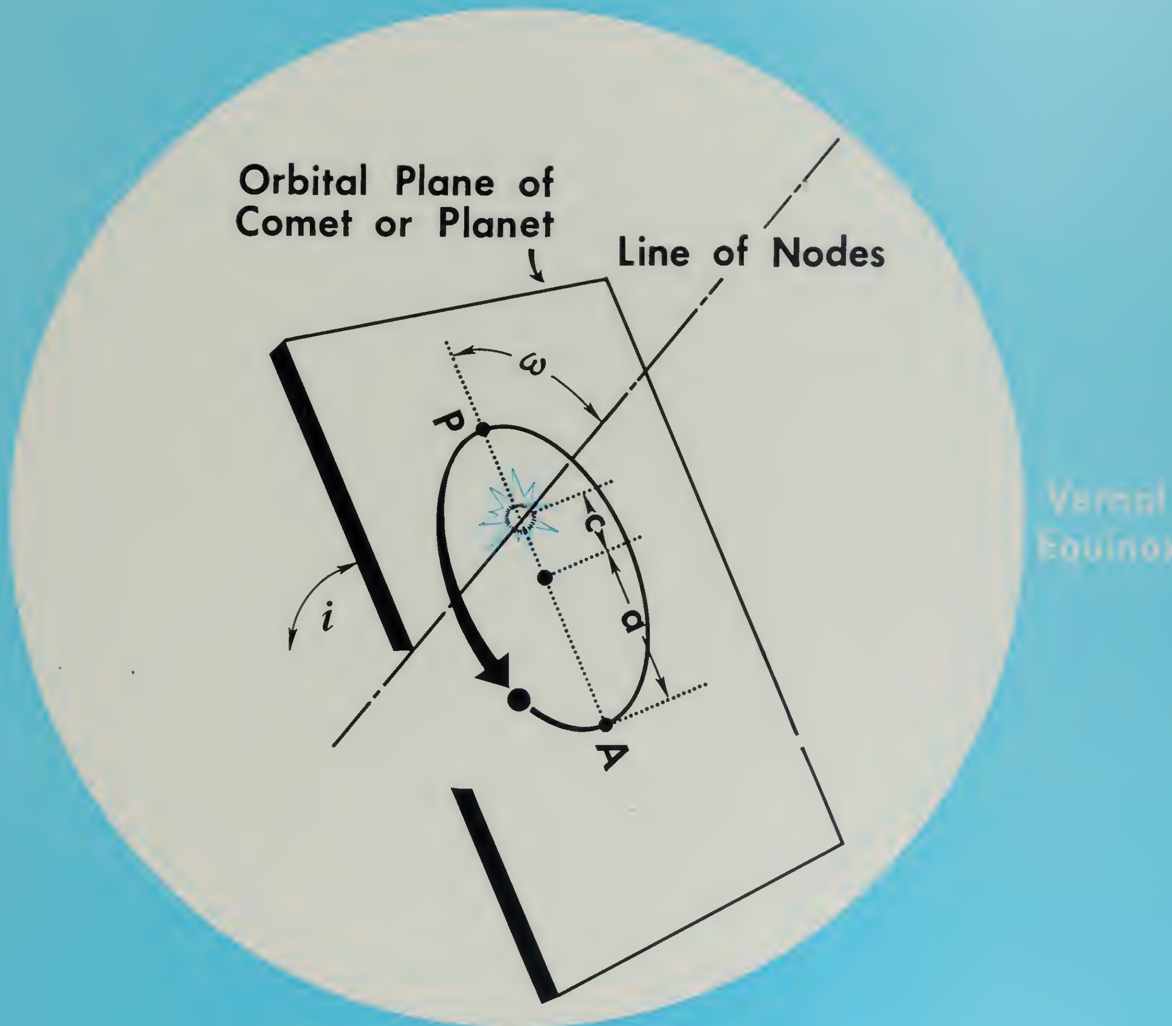
Overlay A — The sun and the Vernal Equinox are shown. This overlay serves as a base for overlays B and C.

Overlay B — The orbital plane of a planet with the elements of an elliptical path are indicated.

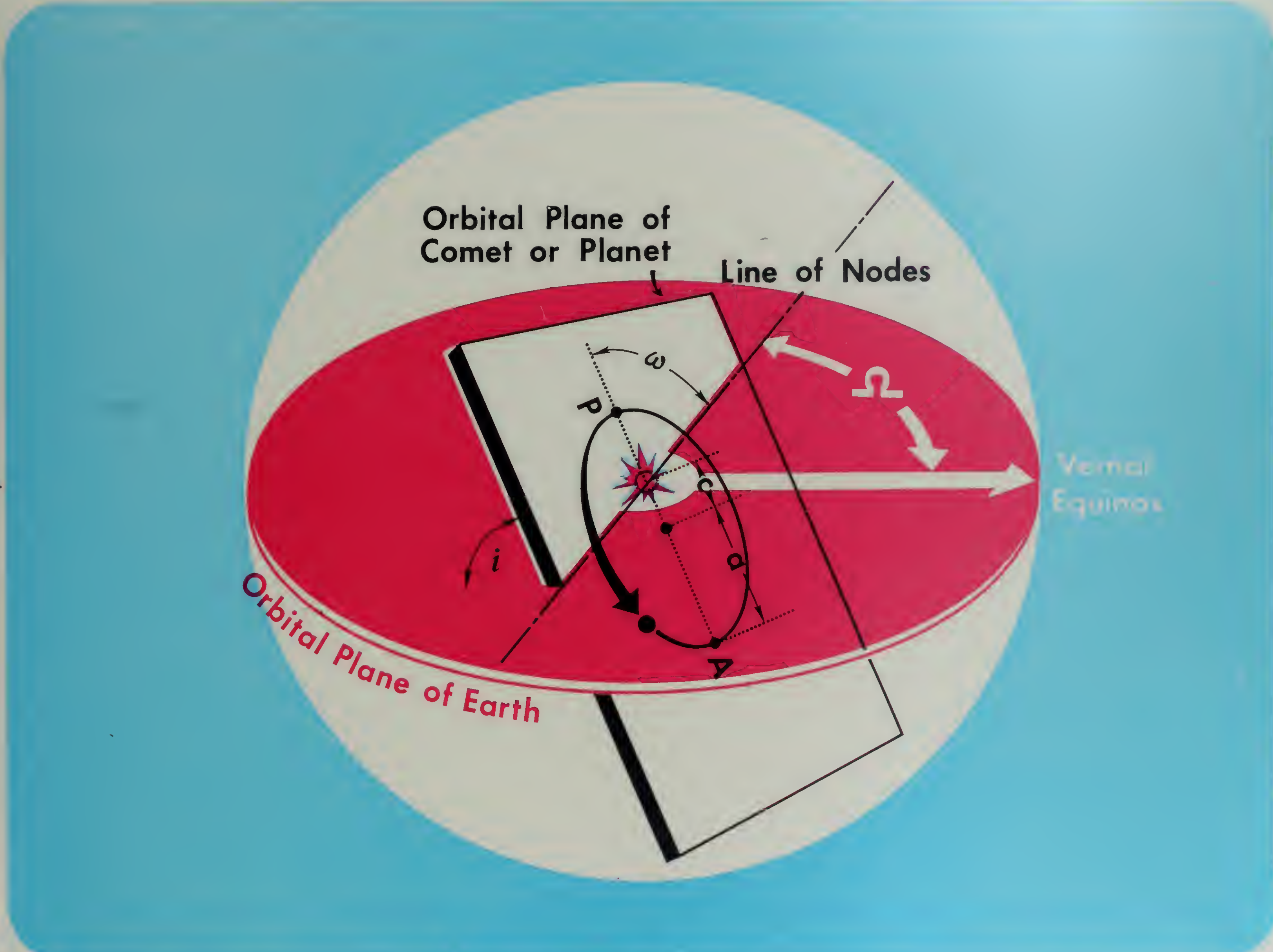
c = one-half distance between the foci
a = semi-major axis
A = aphelion
P = perihelion
(e = eccentricity [$e = c/a$])

Overlay C — The plane of the earth's orbit, known as the plane of the ecliptic, is added. The remaining elements for determining an orbit are shown.

ω = argument of the perihelion
Ω = longitude of the ascending node
i = inclination


Orbital Plane of
Comet or Planet
Line of Nodes
ω
P
c
a
A
i
Vernal
Equinox

A
B
C


Orbital Plane of
Comet or Planet
Line of Nodes
ω
Ω
P
c
a
i
A
Vernal
Equinox
Orbital Plane of Earth

Motion Under a Central Force

Motion Under a Central Force

This transparency follows Newton's analysis of motion as presented in Proposition I of the *Principia*. It shows how an orbit forms when an object receives a sequence of blows all directed toward the same point.

Overlay A — Equal interval positions of a body moving with uniform speed in a straight line.

Overlay B — Kepler's Law of Areas applies in this example of uniform rectilinear motion. As shown by the two blue triangles. an observer at O will see equal areas swept out by the moving object. The areas can be shown to be equal because the bases are equal and the altitudes (dashed line) of both triangles are identical.

Overlay C — This shows the result of a blow on the object directed toward O as it passes point B. The blow is such that if the object were stationary at B, it would move to, say, B′ in the time interval. But the object is moving and if left alone would travel to C. Thus, the result of the blow on the moving object is that it moves to C′, a displacement which is the vector sum of the displacements to C and B′.

Overlay D — The area of the red triangle can be shown to be equal to the area of the light blue one. With the aid of the construction lines you can show that the altitudes of the two triangles are equal. Both triangles have the same base, OB. The areas swept out by the two triangles in equal time intervals will be equal regardless of the magnitudes of the blows. Remove overlays B, C, and D before adding overlay E.

Overlay E — This suggests what will happen if the process of applying blows toward O is continued. Presumably the eventual path will be smooth if the time intervals are made vanishingly small and the forces applied continuously.

Motion Under a Central Force

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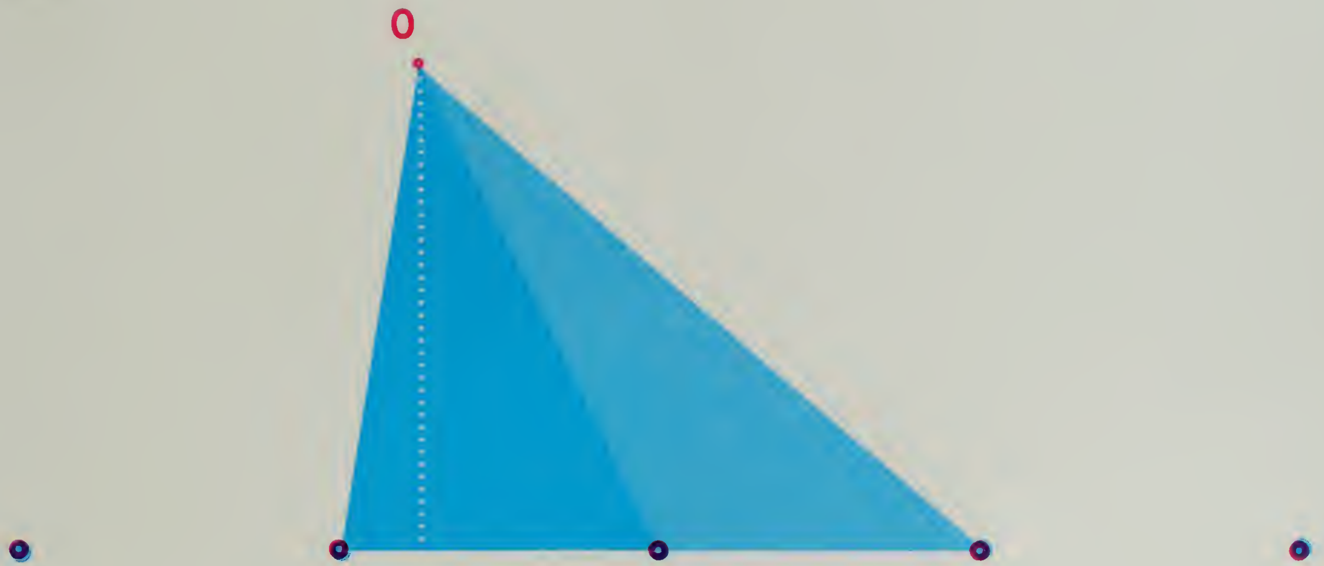
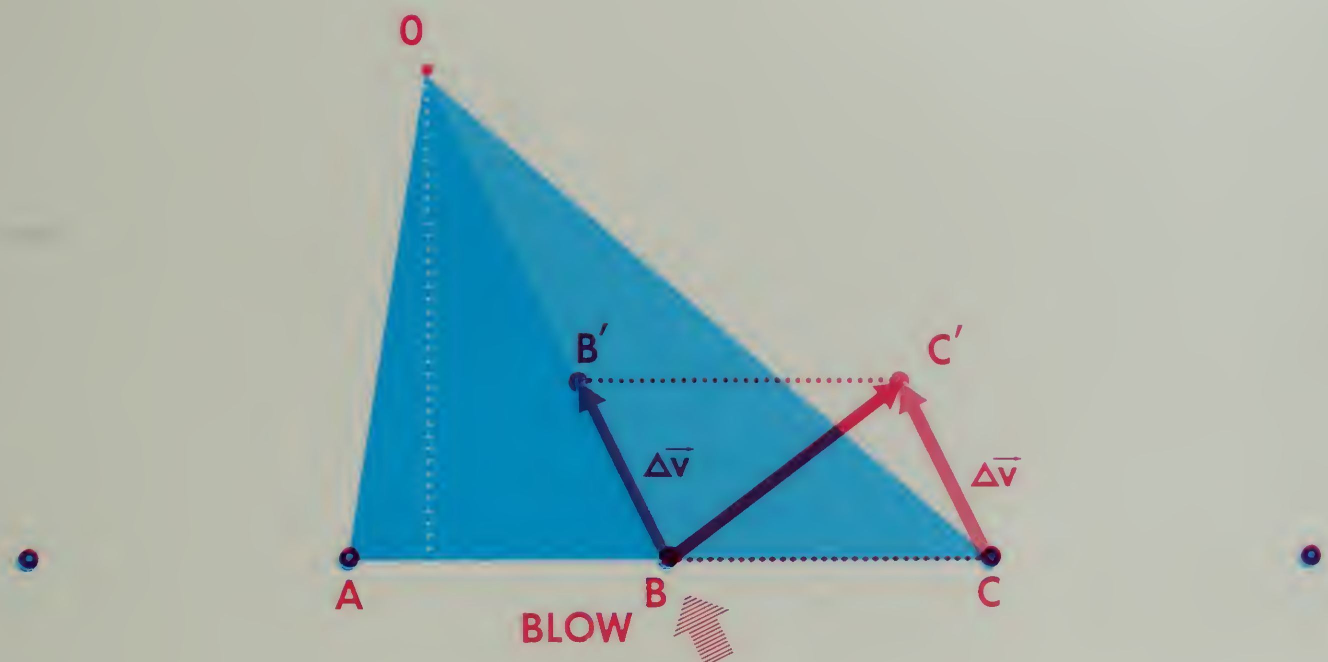
T-18

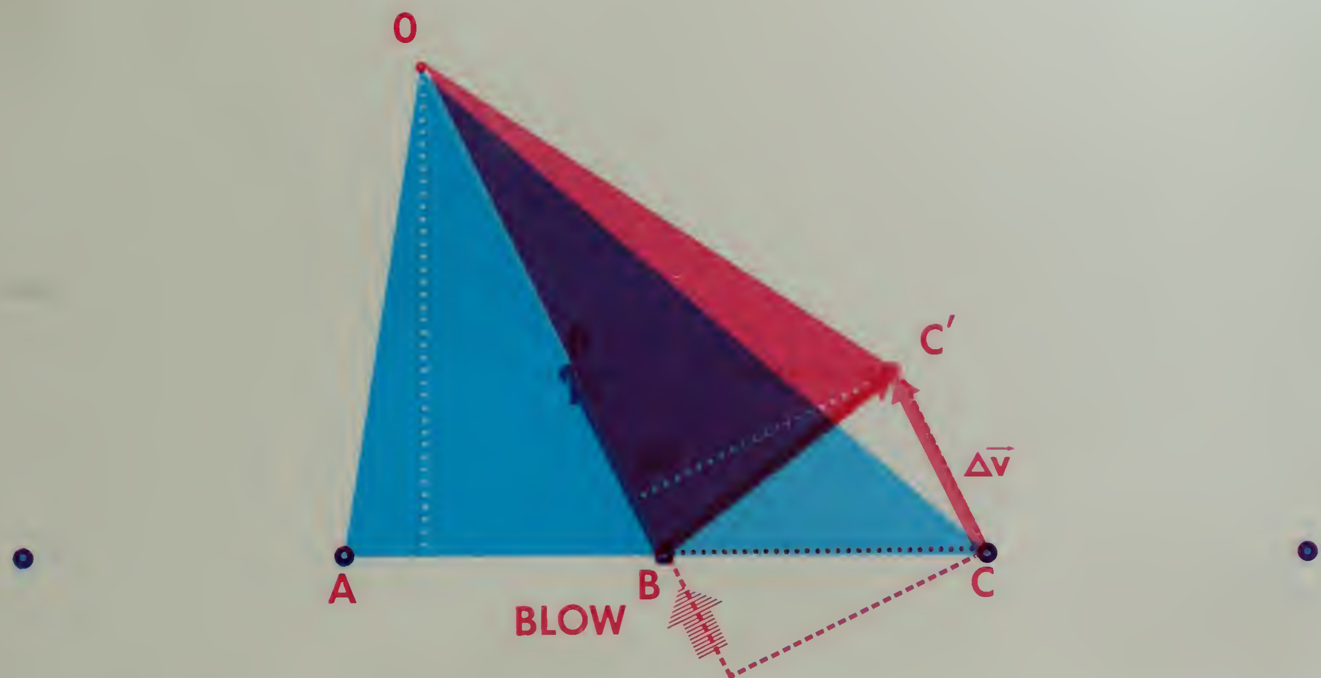
A

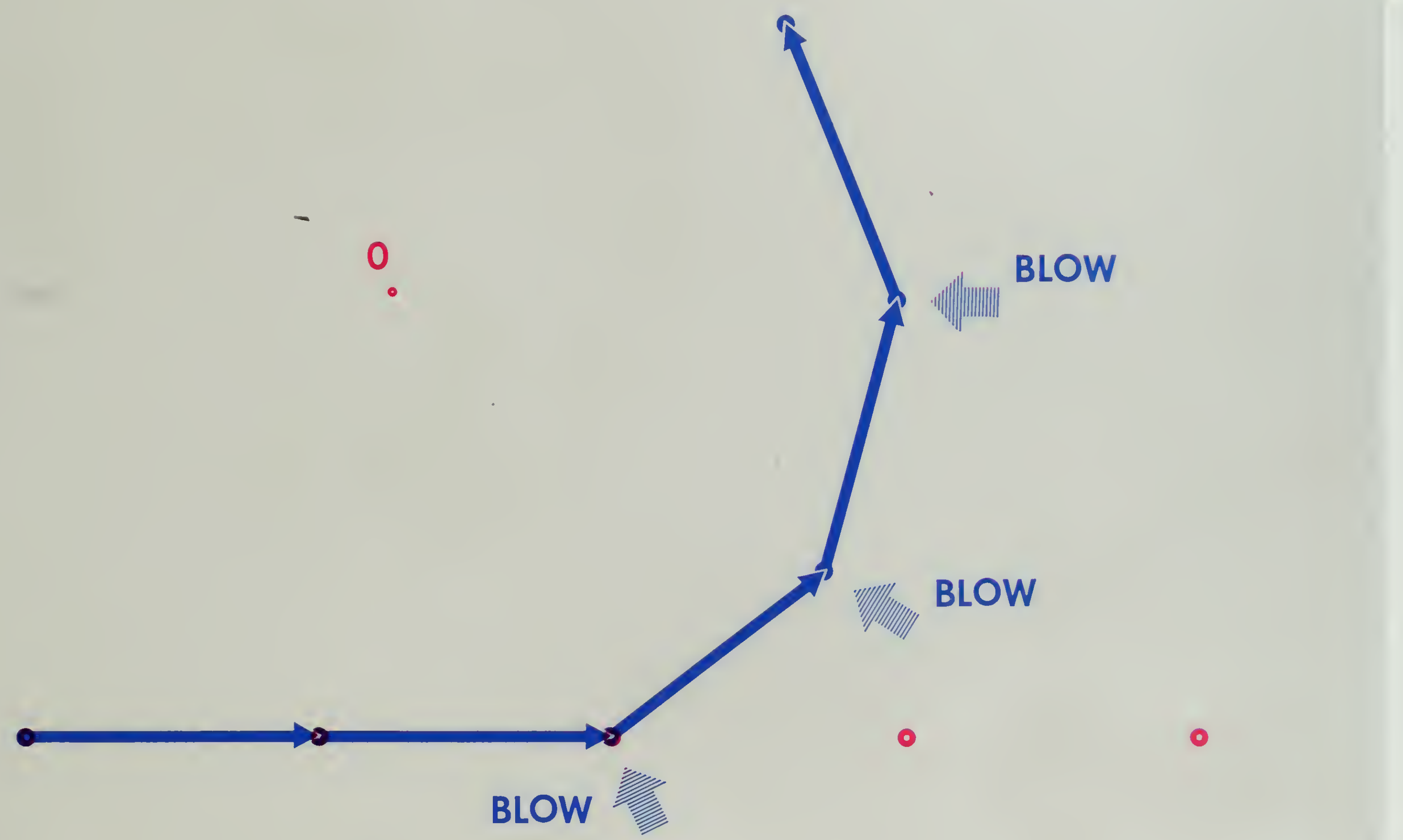
0

A
B




O
B′
C′
Δv⃗
Δv⃗
A
B
C
BLOW


O
C′
$\Delta\vec{v}$
A
B
C
BLOW


A
E
O
BLOW
BLOW
BLOW