

THE SEASONS

THE TEMPERATURE ON EARTH IS DETERMINED BY THE AMOUNT OF ENERGY IT RECEIVES FROM THE SUN.

THE SUN'S ENERGY OUTPUT IS 4×10^{26} W AND AT A DISTANCE OF 1 AU = 150,000,000 km WE RECEIVE 1.4 kW/m^2 PERPENDICULAR TO THE SUNRAYS.

THE SEASONS ARE NOT CAUSED BY CHANGES IN THE DISTANCE TO THE SUN - THE EARTH-SUN DISTANCE VARIES BY 1.7%.

THE SEASONS ARE CAUSED BY $23\frac{1}{2}^\circ$ TILT OF THE EARTH'S ROTATIONAL AXIS RELATIVE TO THE VERTICAL TO THE ECLIPTIC AND BY FIXED DIRECTION OF ROTATIONAL AXIS RELATIVE TO THE STARS

(THE DIRECTION CHANGES BY ABOUT 1.4° EVERY 100 YEARS).

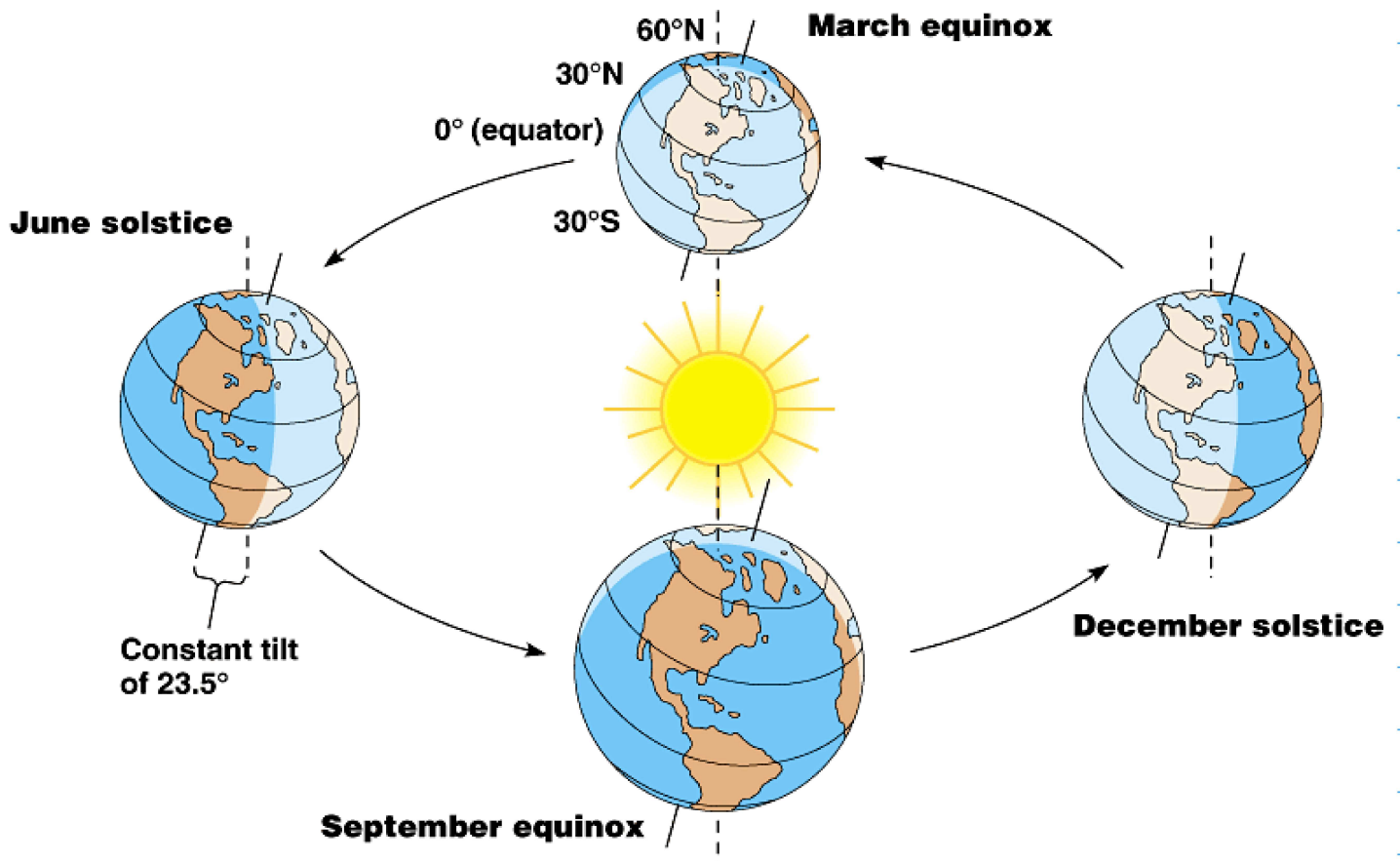
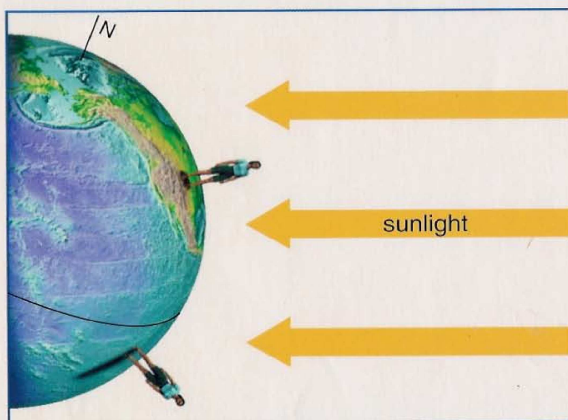
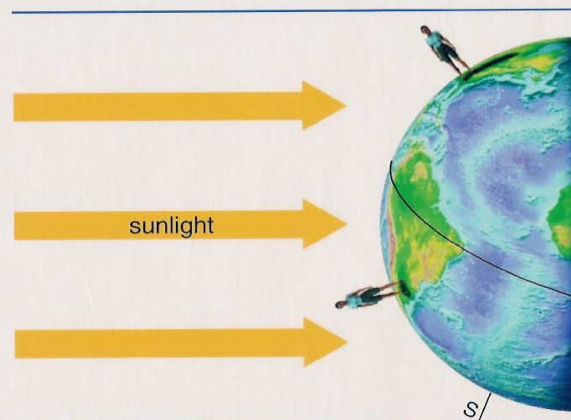


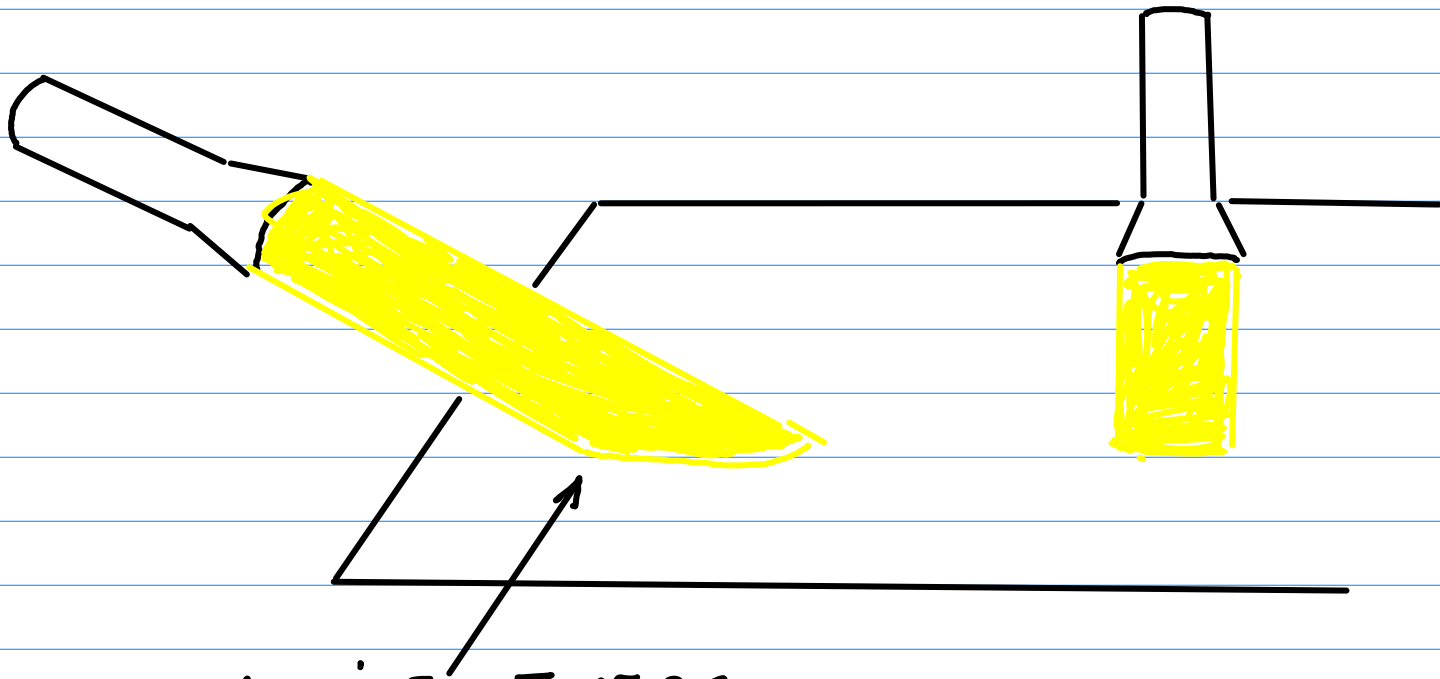
Figure 2.15b seasons



Summer Solstice: Midday sunlight strikes Earth more directly in the Northern Hemisphere—meaning the Sun is higher in the sky and casts smaller shadows—than in the Southern Hemisphere.

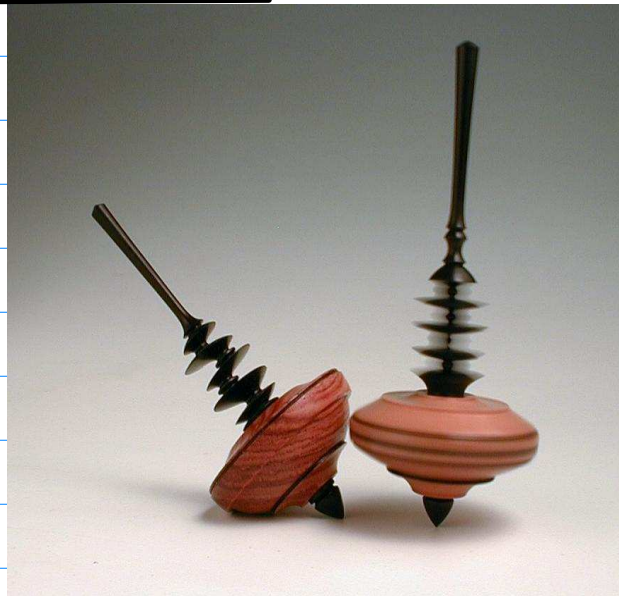


Winter Solstice: The situation is reversed from the summer solstice, with midday sunlight striking the Southern Hemisphere more directly and the Northern Hemisphere less directly.



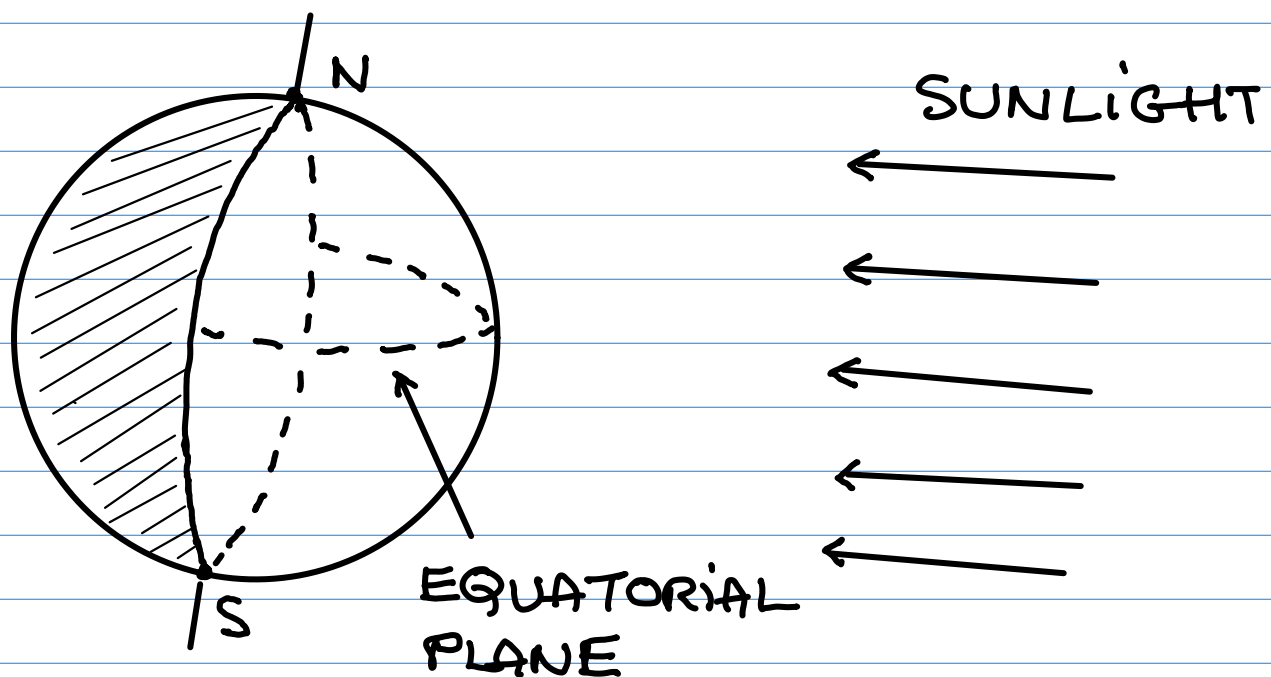
A GIVEN ENERGY
OVER A LARGER
AREA - LESS ENERGY
PER UNIT AREA

NOTE: THE EARTH'S ROTATIONAL AXIS KEEPS
THE SAME DIRECTION BECAUSE OF THE CONSERVATION
OF ANGULAR MOMENTUM. ANALOGY: A SPINNING TOP.

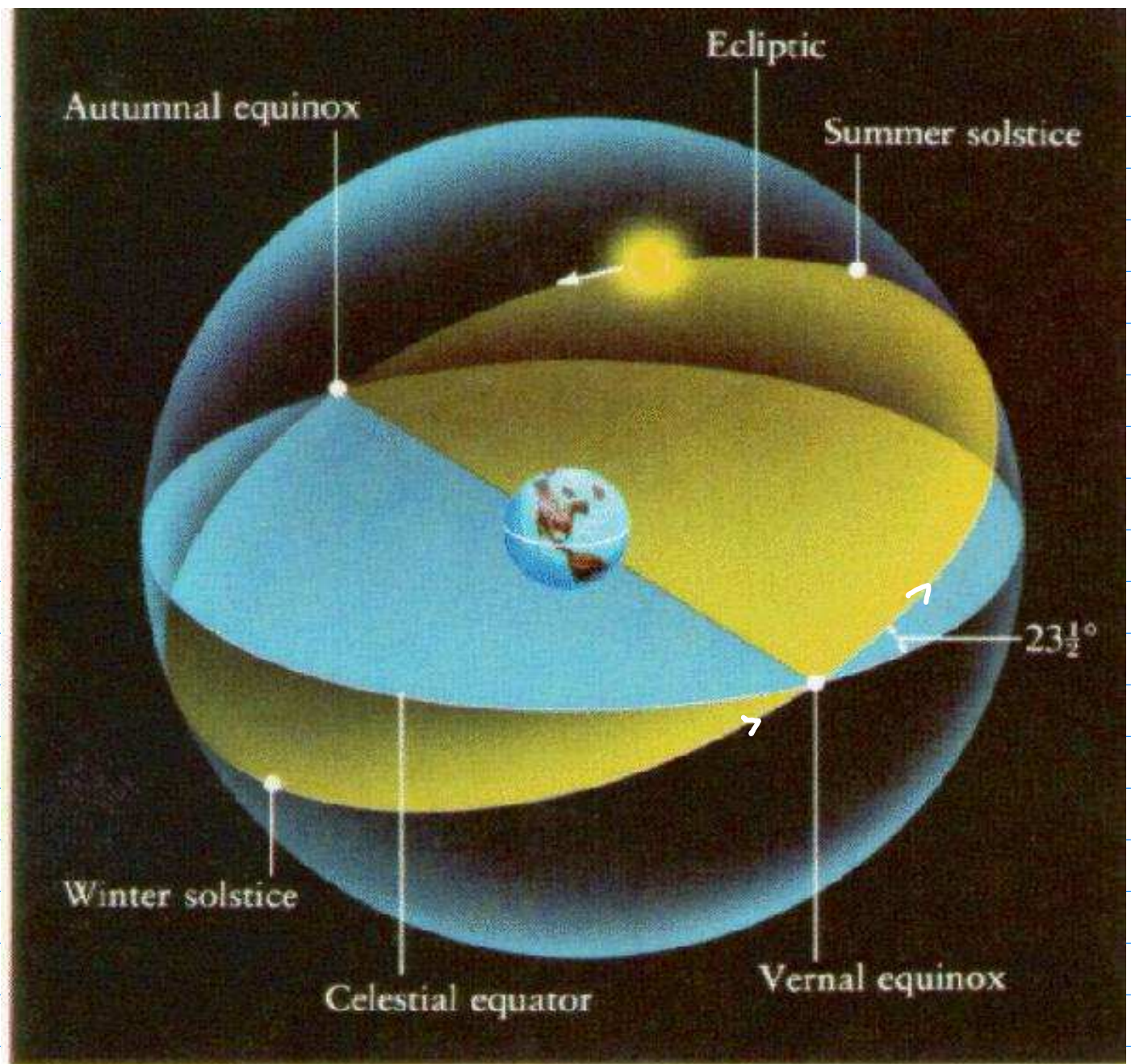


VERNAL EQUINOX, MARCH 20, THE FIRST DAY OF SPRING IN THE NORTHERN HEMISPHERE

NEITHER OF THE TWO POLES IS TIPPED MORE TOWARD THE SUN: NORTH-SOUTH AXIS IS PERPENDICULAR TO THE SUNLIGHT.

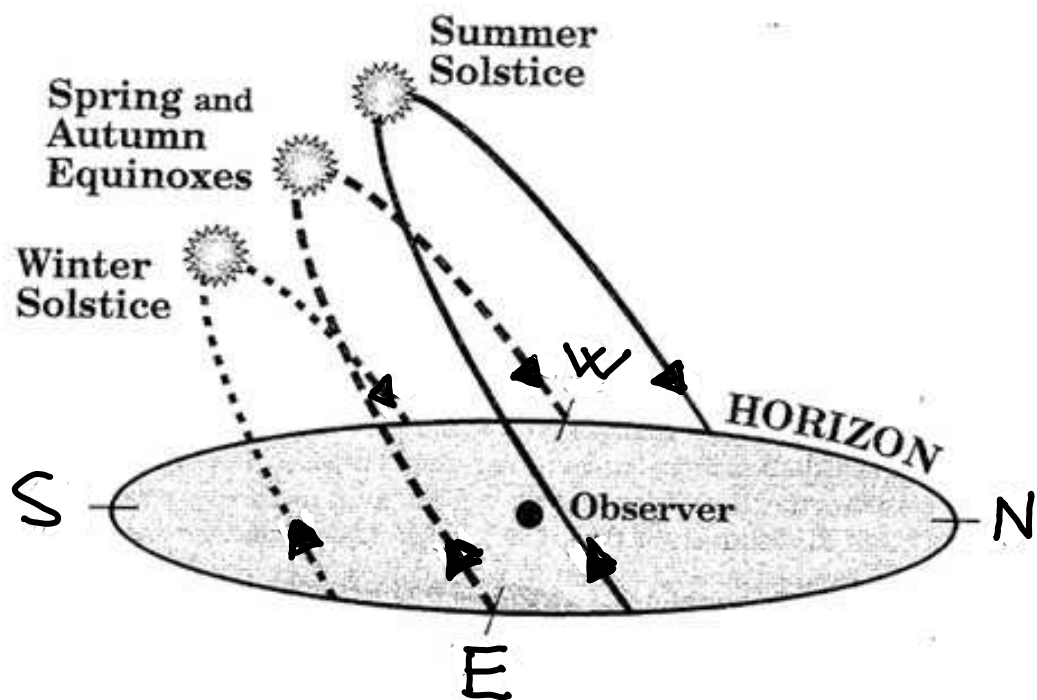


SINCE N-S AXIS IS PERPENDICULAR TO THE EQUATORIAL PLANE, THE SUNLIGHT IS PARALLEL TO THE EQUATORIAL PLANE. HENCE, THE SUN IS ON CELESTIAL EQUATOR ON THAT DAY:



BEFORE THE VERNAL EQUINOX THE SUN WAS BELOW THE CELESTIAL EQUATOR, AND AFTER THE VERNAL EQUINOX THE SUN IS ABOVE THE CELESTIAL EQUATOR. ON VERNAL EQUINOX THE ECLIPTIC CROSSES THE CELESTIAL EQUATOR.

ON VERNAL EQUINOX THE SUN RISES DIRECTLY EAST AND IT SETS DIRECTLY WEST:



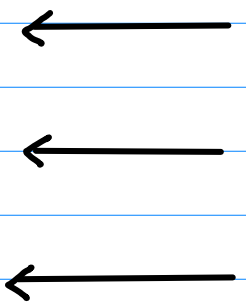
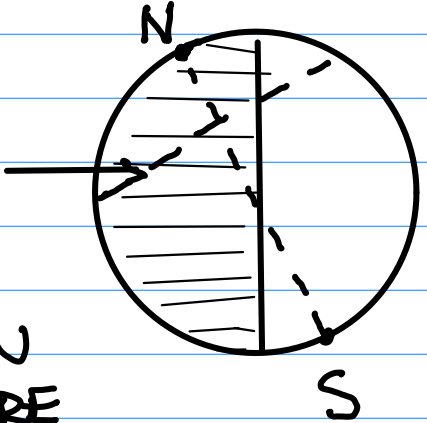
AFTER THE VERNAL EQUINOX THE SUN RISES NORTH OF EAST AND SETS NORTH OF WEST.

ON VERNAL EQUINOX DAY AND NIGHT ARE OF ABOUT EQUAL LENGTH. AFTER THE VERNAL EQUINOX THE DAYS ARE GETTING LONGER AND THE NIGHTS SHORTER AS THE NORTHERN HEMISPHERE TIPS MORE TOWARD THE SUN:

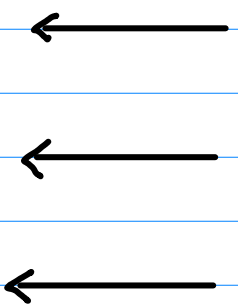
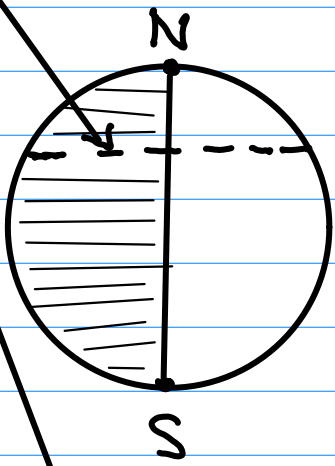
SUNLIGHT

BEFORE VERNAL EQUINOX:

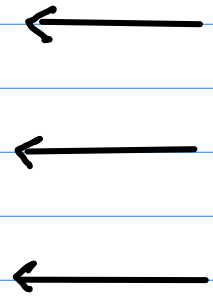
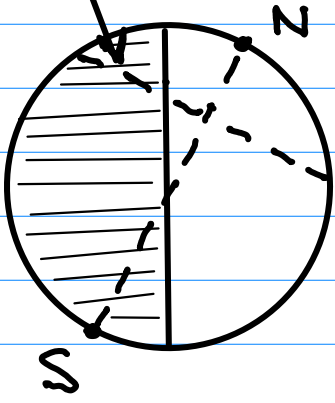
A GIVEN LATITUDE IN THE NORTHERN HEMISPHERE



ON VERNAL EQUINOX:



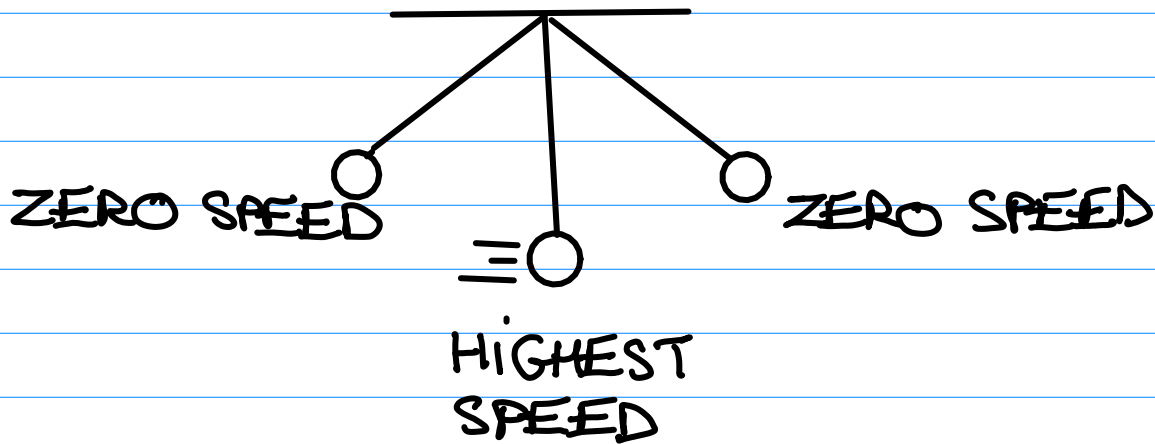
AFTER VERNAL EQUINOX:



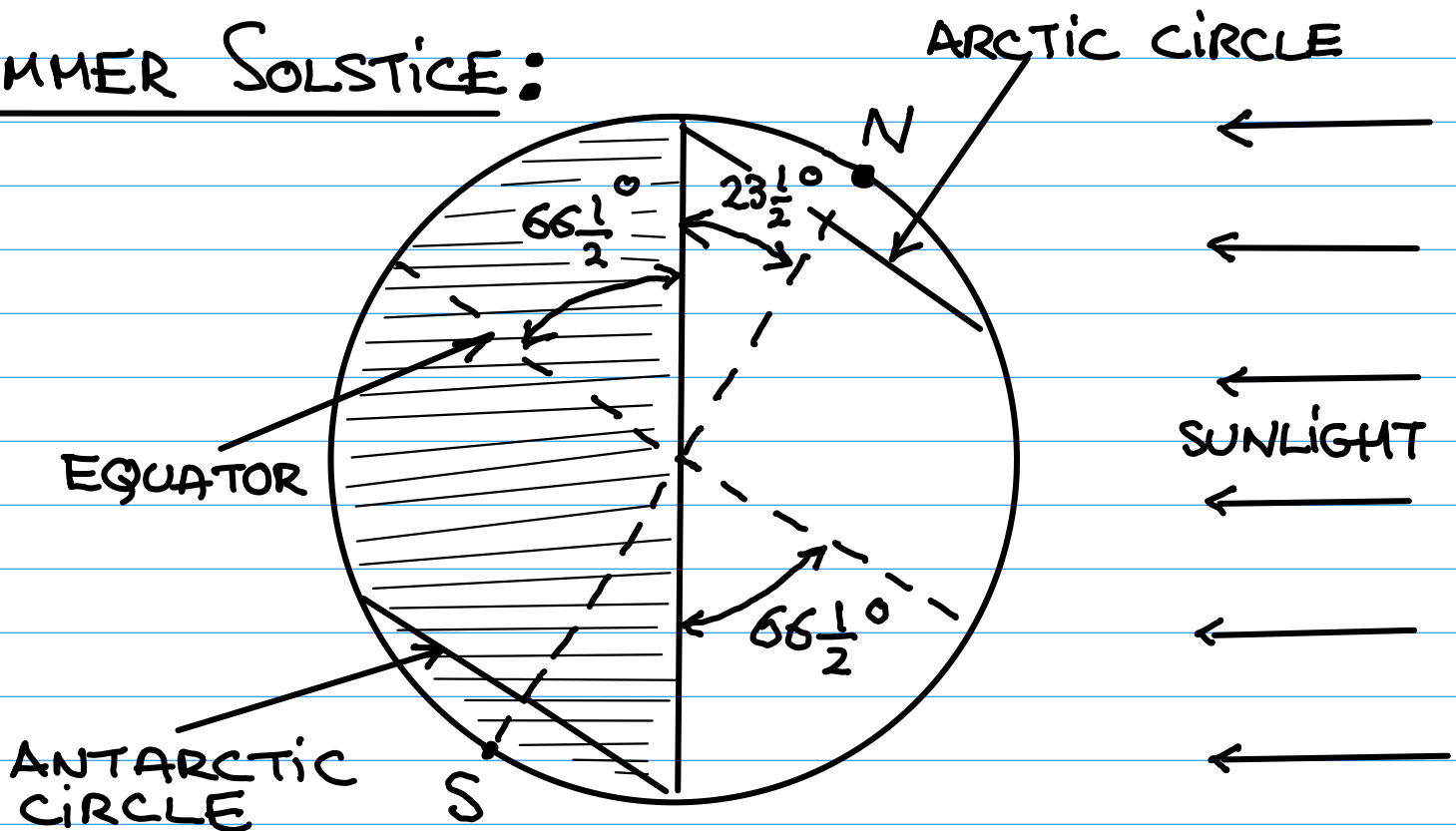
SUMMER SOLSTICE, JUNE 21, THE FIRST DAY OF SUMMER IN THE NORTHERN HEMISPHERE: THE NORTH POLE IS TIPPED TOWARD THE SUN BY THE LARGEST AMOUNT ($23\frac{1}{2}^{\circ}$).

THE NOON SUN HAS REACHED THE HIGHEST POINT IN THE SKY AND AFTER THAT IT STARTS MOVING LOWER TOWARD THE CELESTIAL EQUATOR. THE CHANGES IN THE POSITION OF THE SUN ARE SLOWEST NEAR THE MAXIMUM AND HENCE THE NAME SOLSTICE.

ANALOGY : PENDULUM

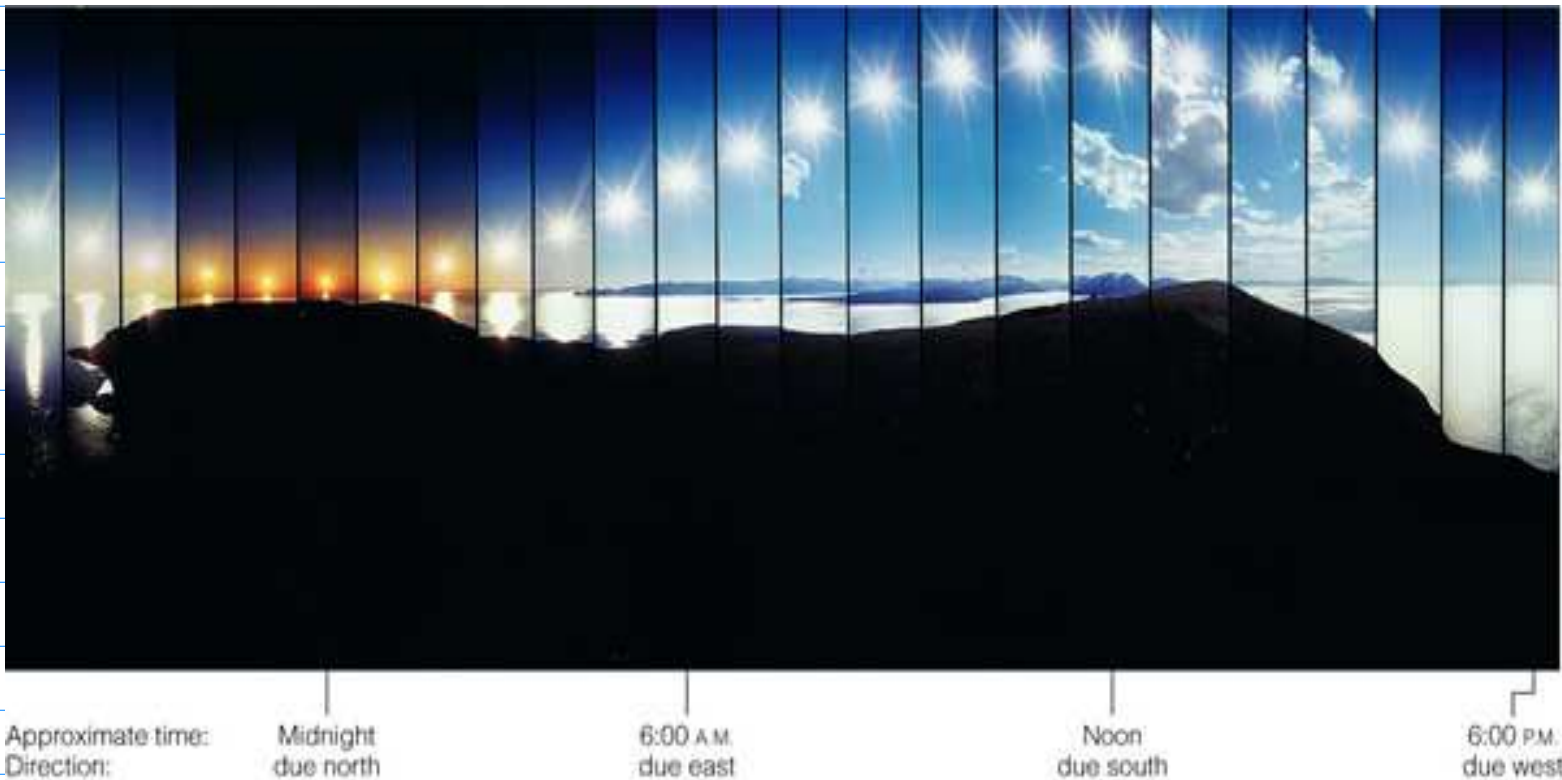


SUMMER SOLSTICE:



THE LONGEST DAY AND THE SHORTEST NIGHT IN THE NORTHERN HEMISPHERE, AND THE OPPOSITE IN THE SOUTHERN HEMISPHERE.

ABOVE THE ARCTIC CIRCLE (LATITUDE $66\frac{1}{2}^{\circ}$ N) THE SUN IS VISIBLE 24 HOURS:



ABOVE THE ANTARCTIC CIRCLE (LATITUDE $66\frac{1}{2}^{\circ}$ S), i.e. FOR THE SOUTHERN LATITUDES GREATER THAN $66\frac{1}{2}^{\circ}$, THE NIGHT IS 24 h LONG.

AFTER THE SUMMER SOLSTICE THE NORTH POLE STARTS TIPPING AWAY FROM THE SUN, THE DAYS ARE GETTING SHORTER AND THE NIGHTS LONGER IN THE NORTHERN HEMISPHERE.

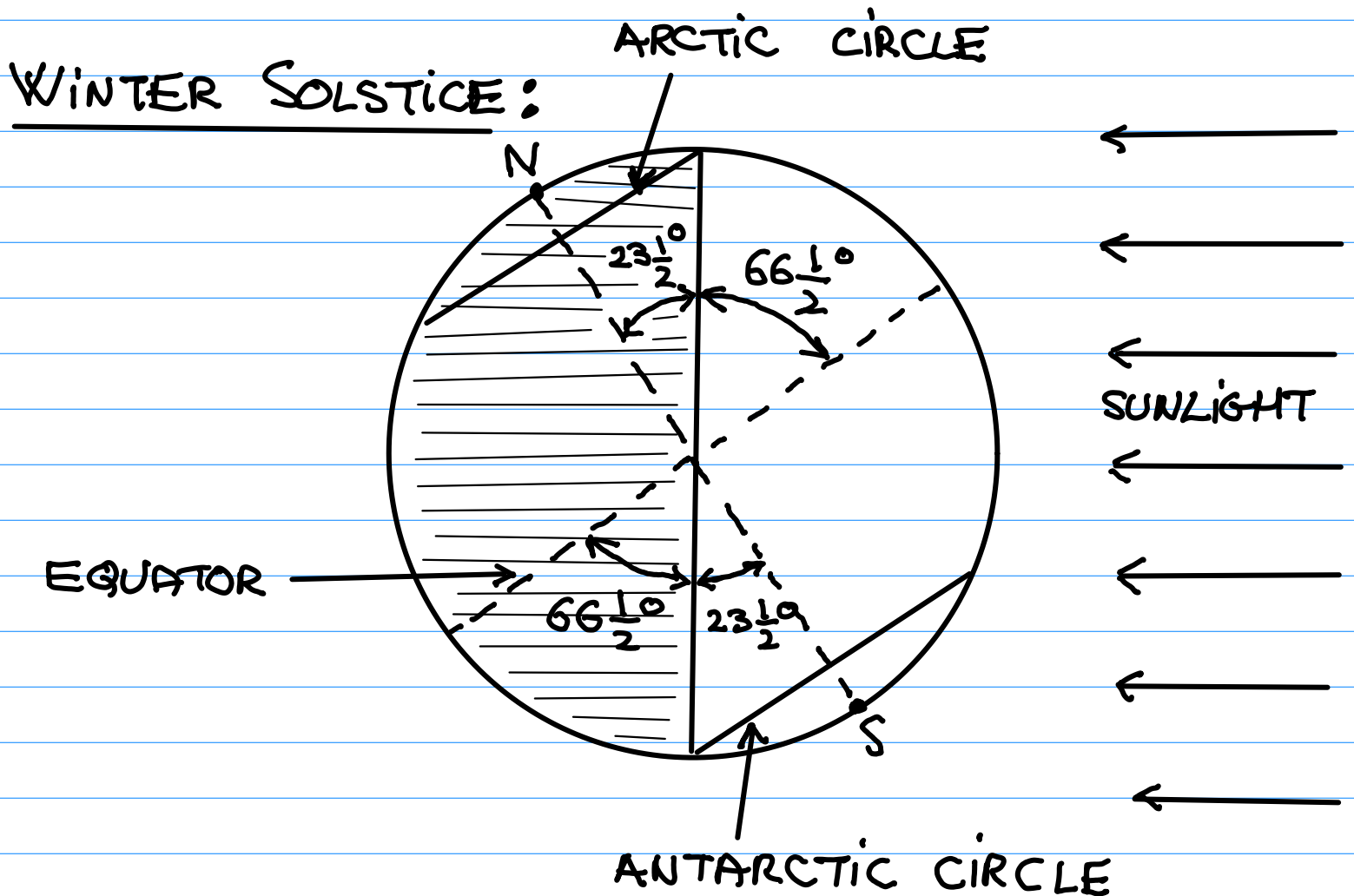
WHY ARE JULY AND AUGUST TYPICALLY HOTTER THAN JUNE? THE REASON IS THERMAL INERTIA - IT TAKES TIME FOR THE LAND AND WATER MASSES TO WARM UP.

AUTUMNAL EQUINOX, SEPTEMBER 22, THE FIRST DAY OF FALL IN THE NORTHERN HEMISPHERE: THE SUN IS ONCE AGAIN ON CELESTIAL EQUATOR, AND EVERYTHING THAT WAS SAID ABOUT THE VERNAL EQUINOX APPLIES TO THE AUTUMNAL EQUINOX.

SUBSEQUENTLY, THE SUN DIPS BELOW CELESTIAL EQUATOR AND IT RISES SOUTH OF EAST AND SETS SOUTH OF WEST. THE DAYS ARE SHORTER THAN NIGHTS.

WINTER SOLSTICE, DECEMBER 21, THE FIRST DAY OF WINTER IN THE NORTHERN HEMISPHERE: THE NORTH POLE IS TIPPED AWAY FROM THE SUN BY THE LARGEST AMOUNT ($23\frac{1}{2}^{\circ}$).

THE NOON SUN HAS REACHED THE LOWEST POINT IN THE SKY AND AFTER THAT IT STARTS MOVING HIGHER TOWARD CELESTIAL EQUATOR.



THE SHORTEST DAY AND THE LONGEST NIGHT IN THE NORTHERN HEMISPHERE AND THE OPPOSITE IN THE SOUTHERN HEMISPHERE.

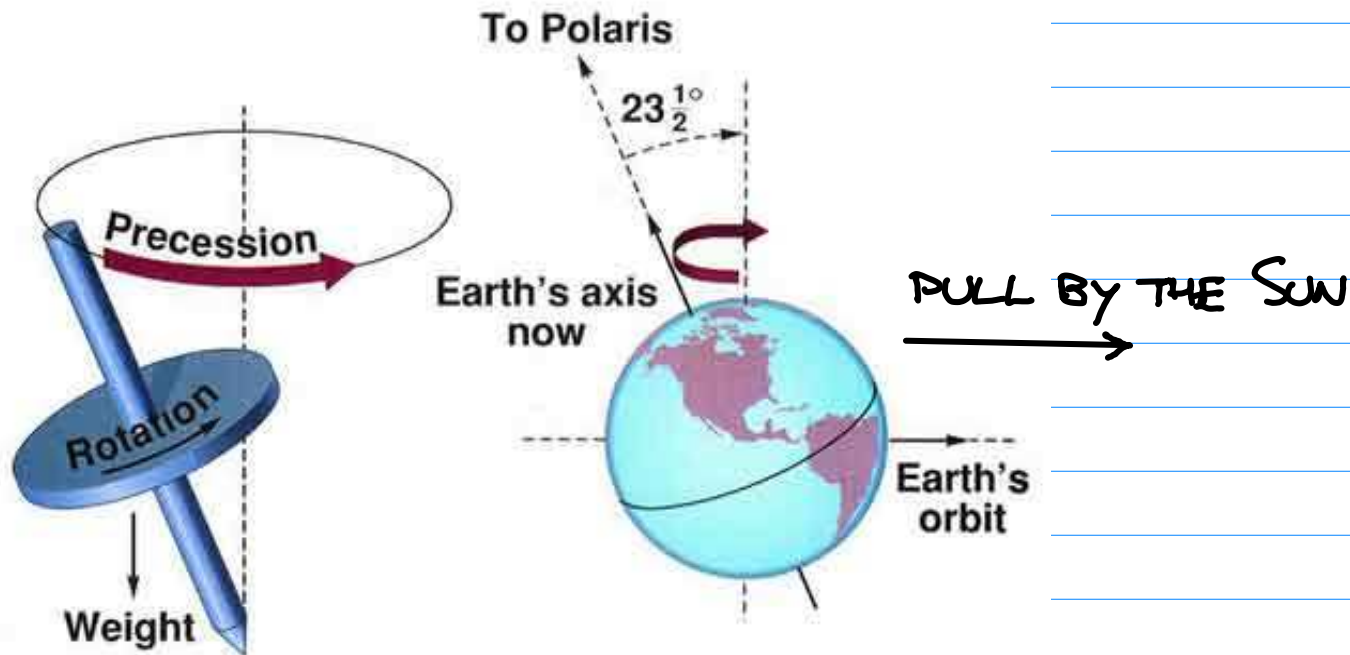
ABOVE THE ARCTIC CIRCLE (LATITUDE $66\frac{1}{2}^{\circ}$ N) THE NIGHT IS 24h LONG.

ABOVE THE ANTARCTIC CIRCLE (LATITUDE $66\frac{1}{2}^{\circ}$ S), I.E. FOR THE SOUTHERN LATITUDES GREATER THAN $66\frac{1}{2}^{\circ}$, THE DAY IS 24h LONG.

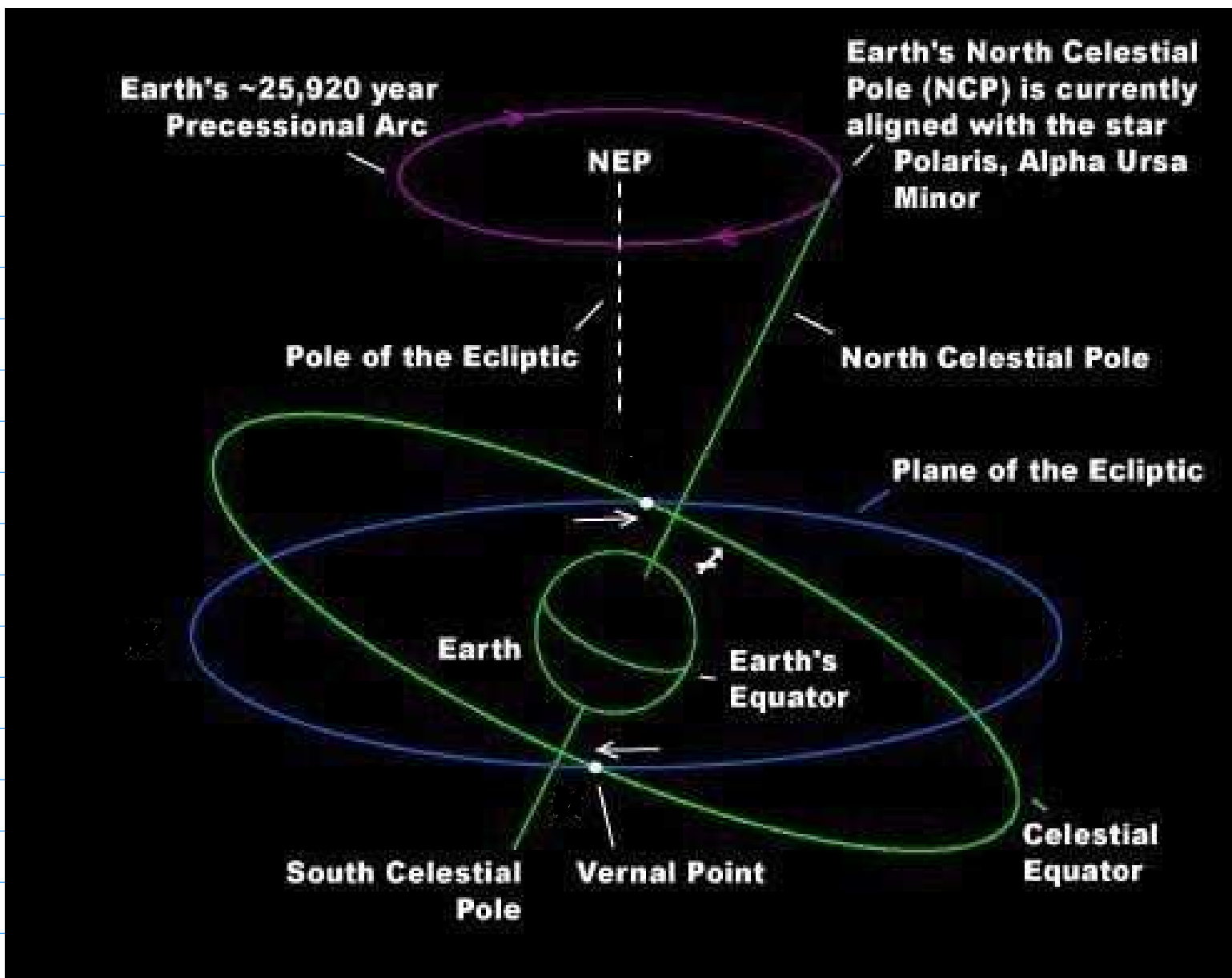
AFTER THE WINTER SOLSTICE THE NORTH POLE STARTS TIPPING TOWARD THE SUN, THE DAYS ARE GETTING LONGER AND THE NIGHTS SHORTER IN THE NORTHERN HEMISPHERE.

JANUARY IS TYPICALLY COLDER THAN DECEMBER BECAUSE OF THE THERMAL INERTIA - IT TAKES TIME FOR THE LAND AND WATER MASSES TO COOL DOWN.

SLOW PRECESSION OF THE EARTH'S ROTATIONAL AXIS



THE EARTH IS NOT A PERFECT SPHERE - IT HAS A SLIGHT BULGE AROUND ITS MIDDLE. THE SUN (AND THE MOON AND THE OTHER PLANETS) EXERT A GRAVITATIONAL PULL ON THAT BULGE TRYING TO SET THE ROTATION AXIS UPRIGHT - PERPENDICULAR TO THE ORBITAL PLANE. AS A RESULT THE ROTATION AXIS PRECESSES ONCE EVERY 26,000 YEARS.



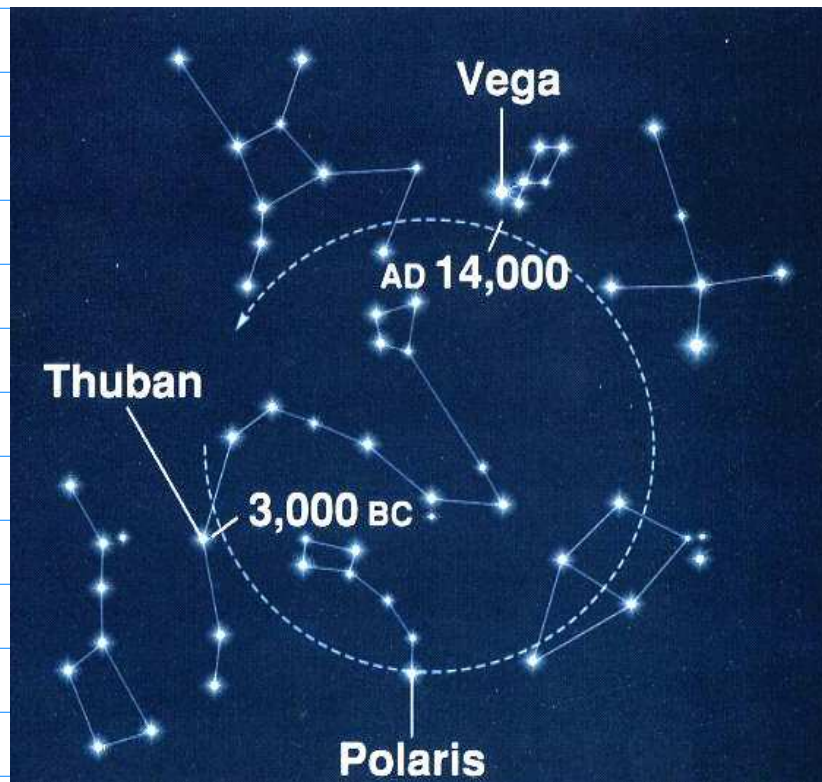
THE DIRECTION OF THE EARTH'S
ROTATIONAL AXIS CHANGES BY

$$\frac{360^{\circ}}{260 \text{ CENTURY}} = 1.4^{\circ} \text{ PER CENTURY}$$

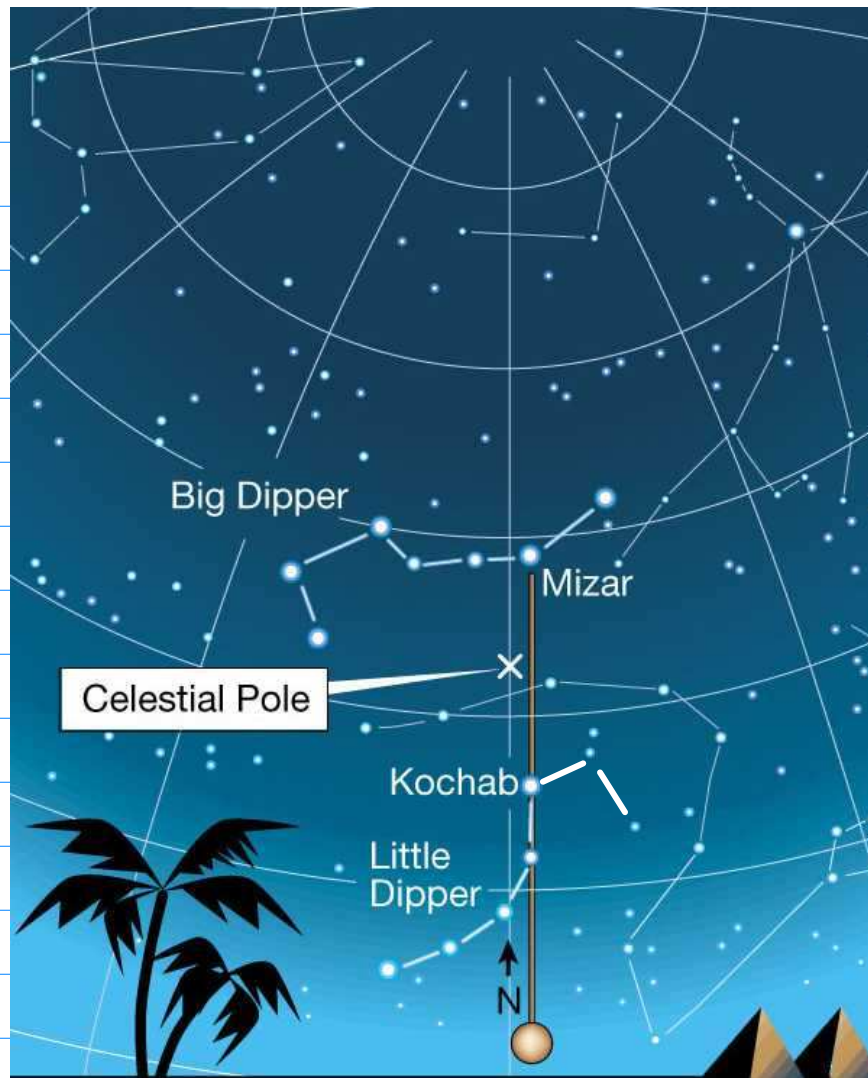
AS A RESULT OF PRECESSION. AS THE
ROTATIONAL AXIS PRECESSES SO DO THE
EQUINOX POINTS (FIRST DISCOVERED BY

HIPPARCHUS IN 127 BC).

THE PRECESSION OF THE ROTATIONAL AXIS IMPLIES THAT THE NORTH CELESTIAL POLE CHANGES ITS POSITION RELATIVE TO THE STARS. AT PRESENT IT IS VERY CLOSE TO POLARIS BUT THAT WAS NOT THE CASE IN THE PAST NOR WILL IT BE THE CASE IN THE FUTURE:

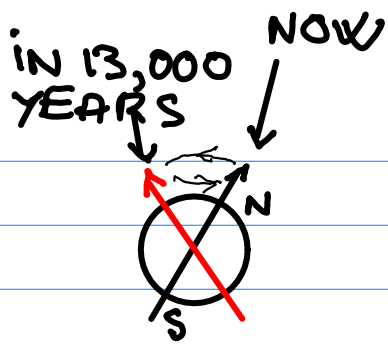


THIS COULD BE USED TO DATE THE EGYPTIAN PYRAMIDS SINCE THEY WERE BUILT SO THAT THEY ARE ALIGNED TOWARD NORTH:

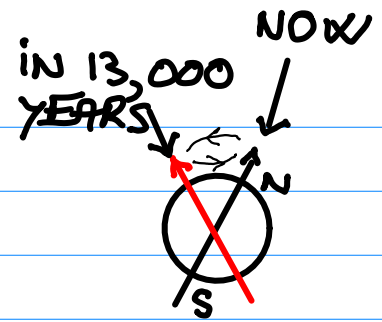
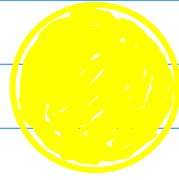


Using this method KATE SPENCE, OF UNIVERSITY OF CAMBRIDGE, DEDUCED THAT THE BEGINNING OF THE CONSTRUCTION OF THE GREAT PYRAMID AT GIZA TOOK PLACE IN 2467 ± 5 BC.

AS A RESULT OF PRECESSION OF THE EARTH'S ROTATIONAL AXIS THE SEASONS SHIFT OVER CENTURIES :



JUNE 21 (NOW)

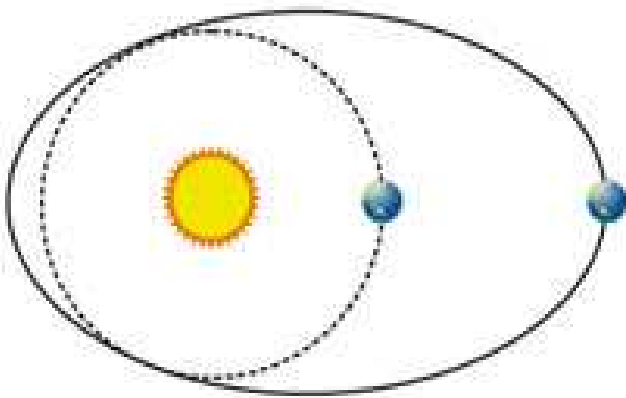


DECEMBER 21 (NOW)

THE CALENDAR IS ADJUSTED OVER TIME SO THAT THE VERNAL EQUINOX IS ALWAYS AROUND MARCH 20. THUS, IN 13,000 YEARS THE SUMMER SOLSTICE WILL ALSO BE AROUND JUNE 21.

MILANKOVIĆ CYCLES:

Milankovitch Cycles



Eccentricity



Obliquity



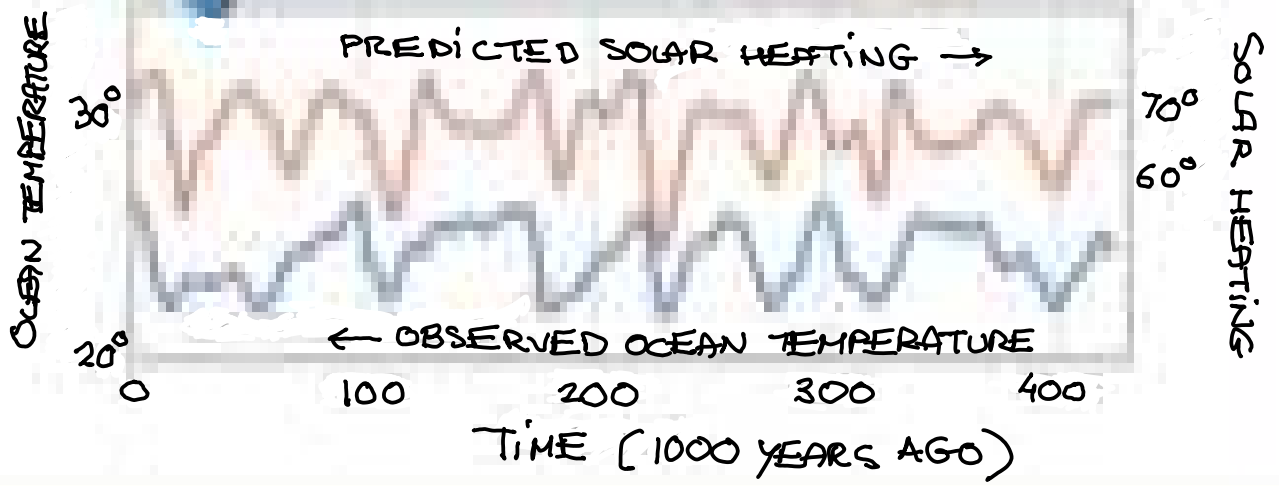
Precession

MILANKOVIĆ PUT FORWARD A THEORY OF PERIODIC CHANGES IN GLOBAL CLIMATE CAUSED BY:

- 1) PERIODIC VARIATIONS IN THE ECCENTRICITY OF THE EARTH'S ORBIT (EVERY 100,000 YEARS);
- 2) PERIODIC CHANGES IN THE TILT OF THE EARTH'S ROTATIONAL AXIS FROM 22.1° TO 24.5° (EVERY 41,000 YEARS);
- 3) PRECESSION OF THE EARTH'S ROTATIONAL AXIS (EVERY 26,000 YEARS).

THESE CYCLES ARE SUPERIMPOSED ON EACH OTHER TO GIVE A PERIODIC CHANGES IN THE EARTH'S CLIMATE.

THE MILANKOVIĆ THEORY HAS BEEN CONFIRMED BY GEOLOGICAL FINDINGS OVER THE LAST 40 YEARS. THE EVIDENCE CAME FROM DATING OF FOSSIL CORAL REEFS ALONG THE SHORE OF PAPUA, NEW GUINEA, WHICH FORMED DURING THE WARM PERIODS.



MILUTIN MILANKOVIĆ