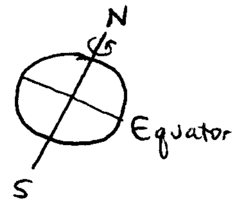
DISTRIBUTION OF SOLAR RADIATION WITH LATITUDE, SEASON, and HOUR.

EARTH'S ROTATION & ORBIT

1. ROTATION.

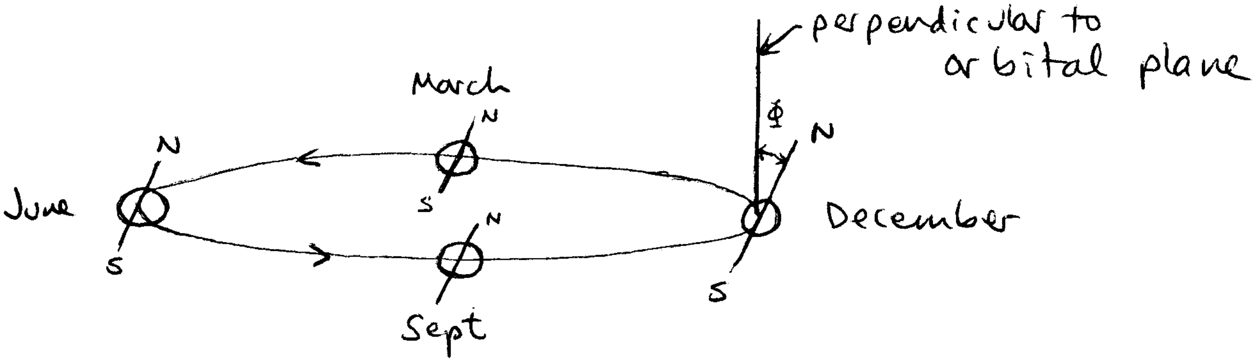
The axis of rotation joins the North and South Poles. The circumference of the planet halfway between N, S poles is the Equator.

Earth rotates to the east, once per day.



2. Relation of rotation axis to the orbital plane

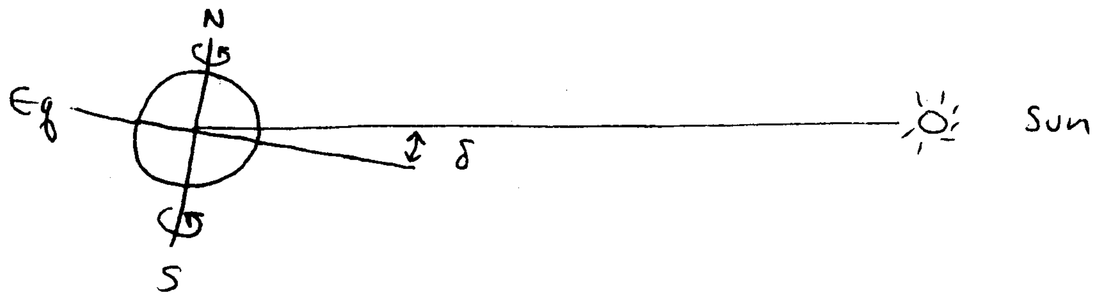
"Tilt" angle Φ is the angle between the axis of rotation and the perpendicular to the orbital plane. This tilt is responsible for the seasons.



For Earth, Φ varies in the range 22° – 24.5°, on a 40,000-year cycle. It is now 23.5° and decreasing.

For Mars, Φ is now 23.9°. It varies between 15° and 35°.

Because the tilt remains constant over the year, the angle between the earth-sun line and the earth's equator varies between $+23.5°$ and $-23.5°$. This angle is called the <u>declination</u>. δ

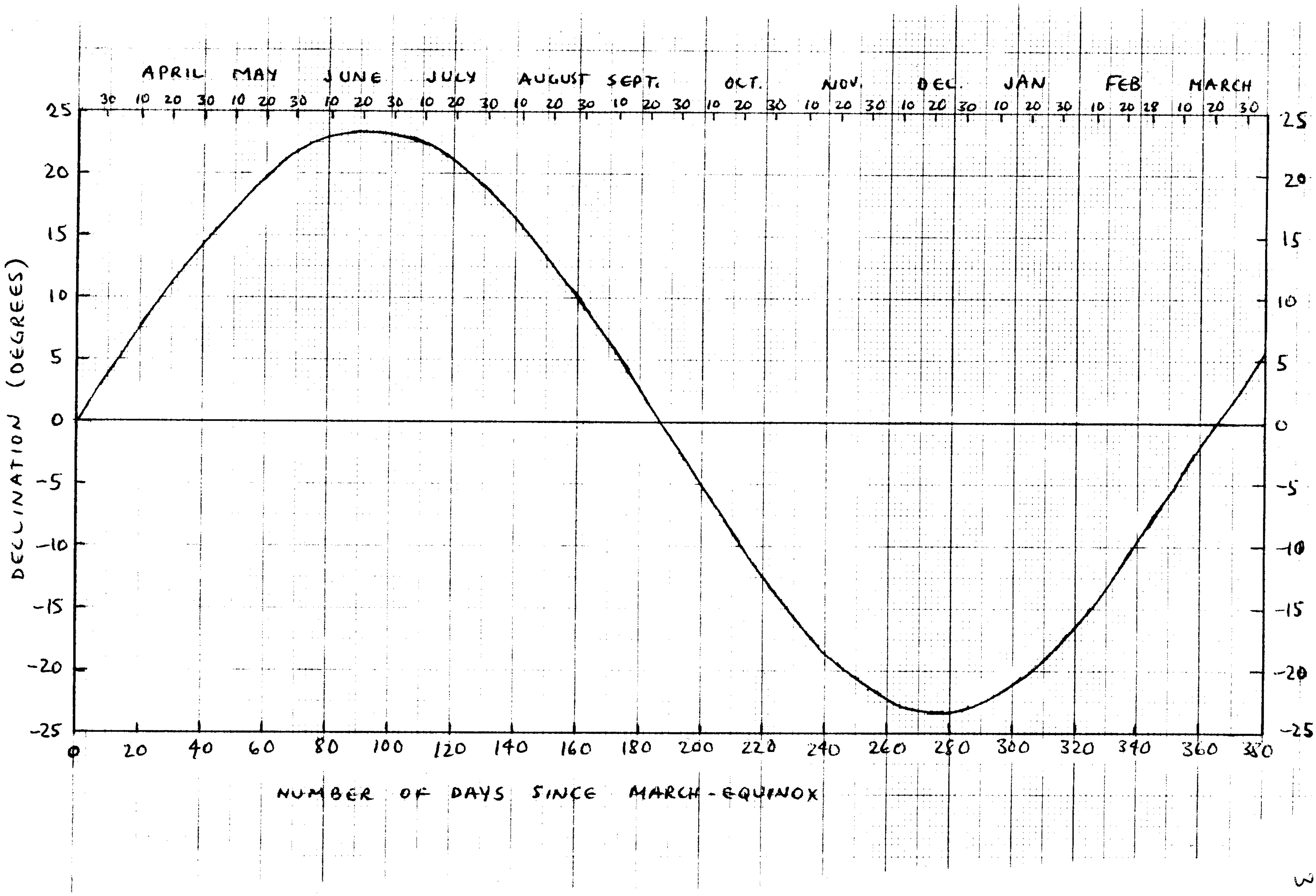


Declination thus also is the latitude where solar beam is vertical at noon.

The <u>time</u> of year when $\delta = 0°$ is called "equinox" ("equal night")
The time of year when $\delta = \pm 23.5°$ is called "solstice".

time of year	declination	sun is vertical at what latitude
June solstice (21 June)	$+23.5°$	23.5°N (Tropic of Cancer)
September equinox (23 Sept)	$0°$	0°N (Equator)
December solstice (22 Dec)	$-23.5°$	23.5°S (Tropic of Capricorn)
March equinox (21 March)	$0°$	0°N (Equator)

STRAHLER, 1975: PHYSICAL GEOGRAPHY page 83



GREEK

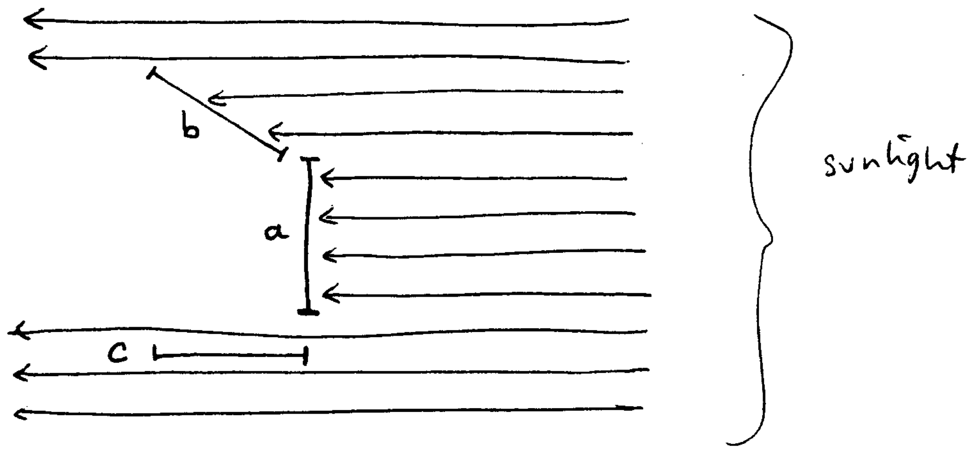
Forms	Name	Sound
Α α	alpha	a.
Β β	beta	b
Γ γ	gamma	g
Δ δ	delta	d
Ε ϵ	epsilon	e
Ζ ζ	zēta	z
Η η	ēta	ē
Θ θ	thēta	th
Ι ι	iota	i
Κ κ	kappa	k
Λ λ	lambda	l
Μ μ	mu	m
Ν ν	nu	n
Ξ ξ	xi	x, ks
Ο ο	omicron	o
Π π	pi	p
Ρ ρ	rhō	r
Σ σ ς	sigma	s
Τ τ	tau	t
Υ υ	upsilon	u
Φ ϕ	phi	ph, f
Χ χ	khi	kh
Ψ ψ	psi	ps
Ω ω	ōmega	ō

B. Radiation received on a surface.

The rate of energy received by a flat surface* of 1 m^2 oriented perpendicular to the solar beam is equal to the solar constant, 1370 Wm^{-2}

*[at the top of earth's atmosphere, at the average earth-sun distance]

A tilted surface receives less than this:

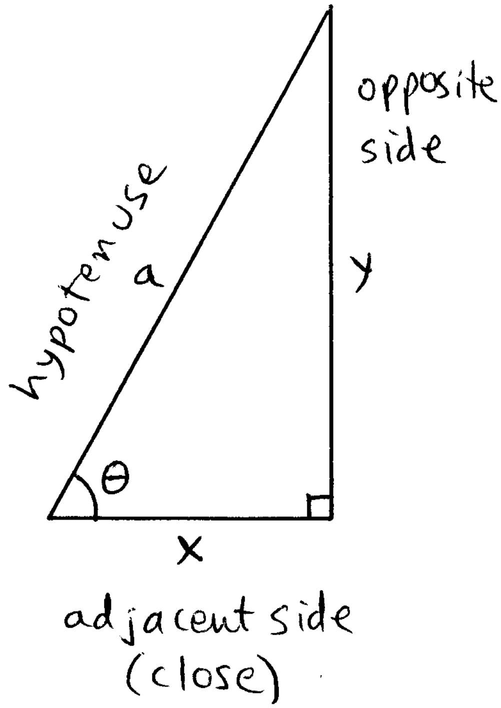


Surface a is perpendicular to the sun and intercepts 1370 Wm^{-2}

Surface b is tilted 60° and intercepts 1370/2 Wm^{-2}

Surface c is tilted 90° and intercepts zero.

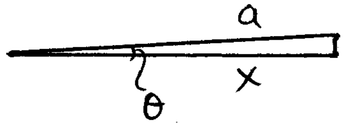
Trigonometry



$$\frac{y}{a} = \sin\theta$$

$$\frac{x}{a} = \cos\theta$$

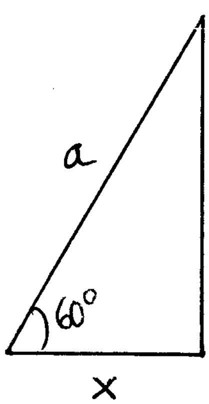
$$\boxed{x = a\cos\theta}$$



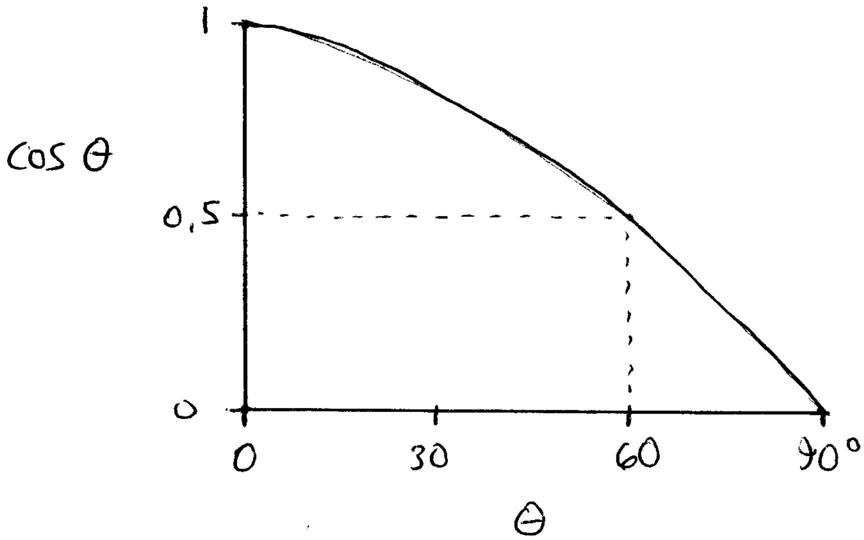
If $\theta = 0$, $x = a$,

$$\frac{x}{a} = \cos\theta = 1$$

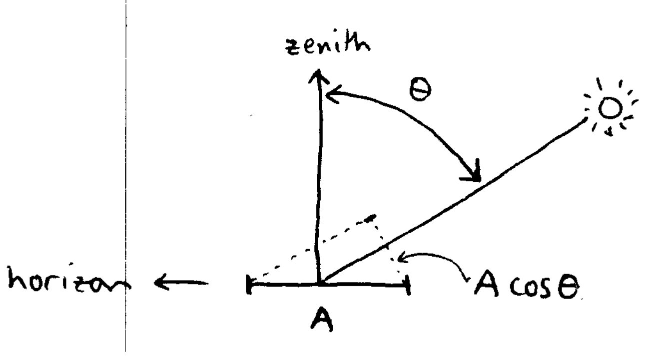
If $\theta = 90°$, $x = 0$, $\frac{x}{a} = \cos\theta = 0$



If $\theta = 60°$, $\frac{x}{a} = \frac{1}{2}$


1
cos θ
0,5
0
0
30
60
90°
θ

Define the **solar zenith angle** θ as the angle <u>from</u> local vertical (or "zenith") down to the solar beam.



"Project" the surface onto a plane perpendicular to the solar beam. The area A (m^2) projects to a smaller area $A \cos\theta$ (m^2).

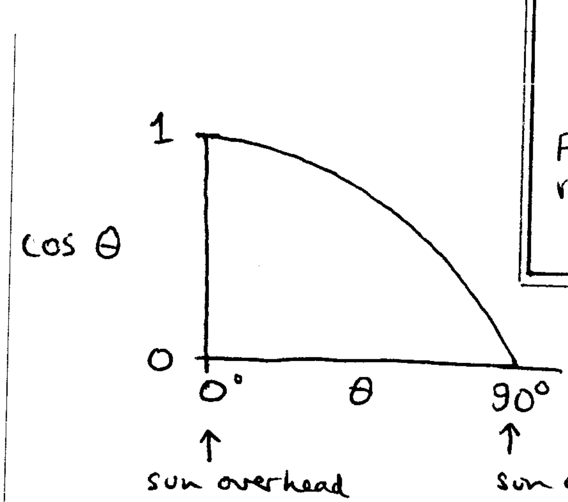
The sunlight incident on the perpendicular area $A\cos\theta$ is spread out over the larger horizontal area A. If the horizontal area were perpendicular to the Sun it would receive the solar constant 1370 Wm^{-2}; because it's not perpendicular it receives only $1370 \cdot \cos\theta$ Wm^{-2}. The cosine is always between 0 and 1:

"<u>The Cosine Law</u>"

$$F = S \cdot \cos\theta \quad (Wm^{-2})$$

F ↑ Flux received

S ↑ solar constant (adjusted for eccentricity)

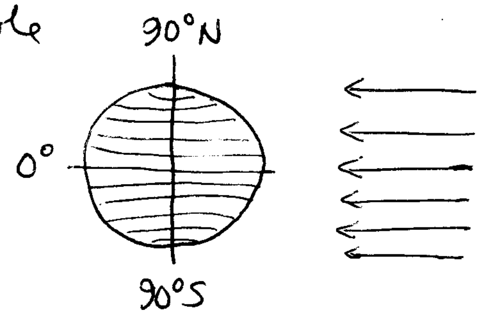


Most earth-surfaces are not perpendicular to the solar beam. The solar beam is vertical only at one point on Earth at any particular time. This point is always somewhere in the "tropics", i.e. between 23.5° N and 23.5° S.

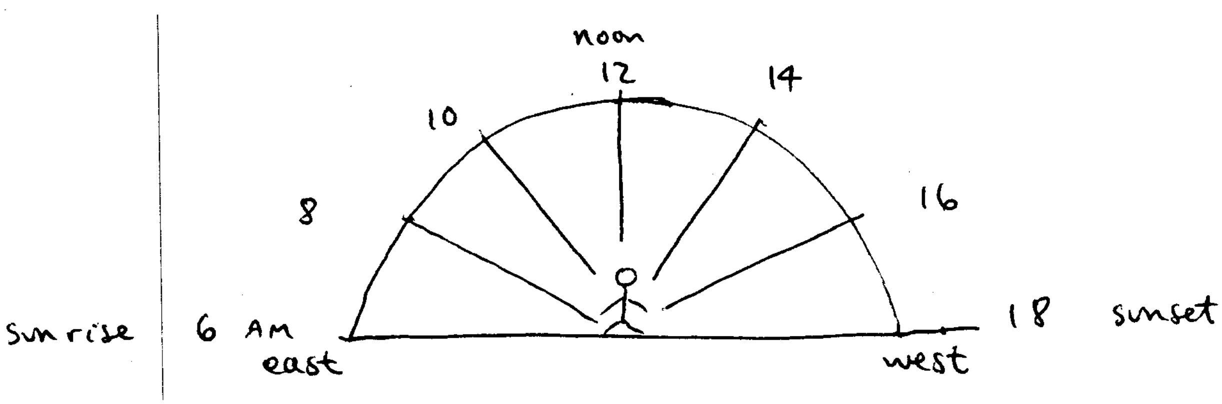
Examples of solar zenith angle

① At noon on the equinox (March or September), $\delta = 0$
The zenith angle θ is equal to the latitude α. $(\alpha = \theta)$

$\theta = 0°$ at equator
$\theta = 90°$ at North Pole, South Pole
$\theta = 47.5°$ at Seattle.



② **On the equinox at the Equator** (21 March, 21 Sept.)

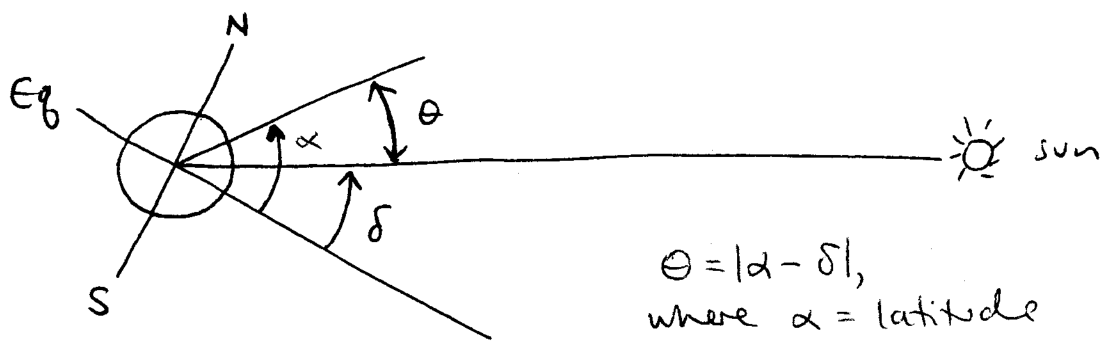


local time	zenith angle θ	$\cos\theta$	incident solar radiation
6:00	90	0.0	0
8:00	60	0.5	0.5 × 1370
9:00	45	0.7	0.7 × 1370
12:00	0	1.0	1370
18:00	90	0.0	0

③ At noon, on any day, at any latitude.

The zenith angle is not equal to the latitude.
You have to subtract the declination.

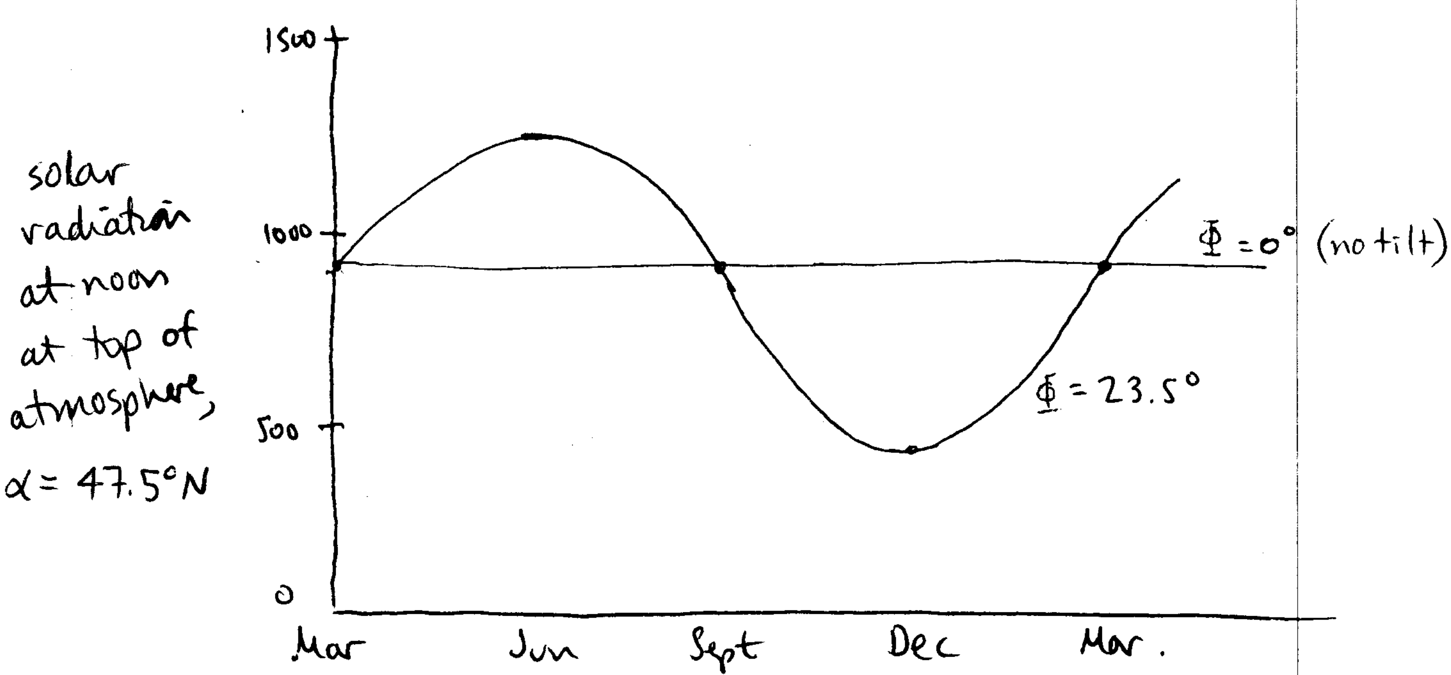
For example at Seattle in June, the sun is high:

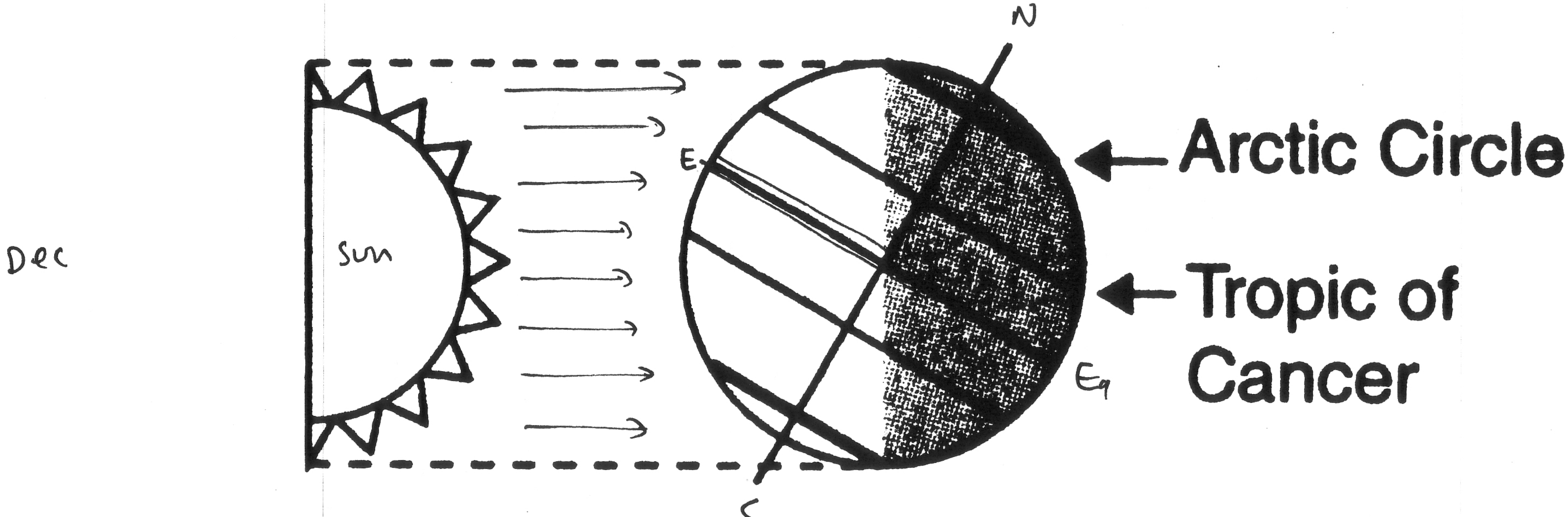


$\theta = |\alpha - \delta|$,
where α = latitude

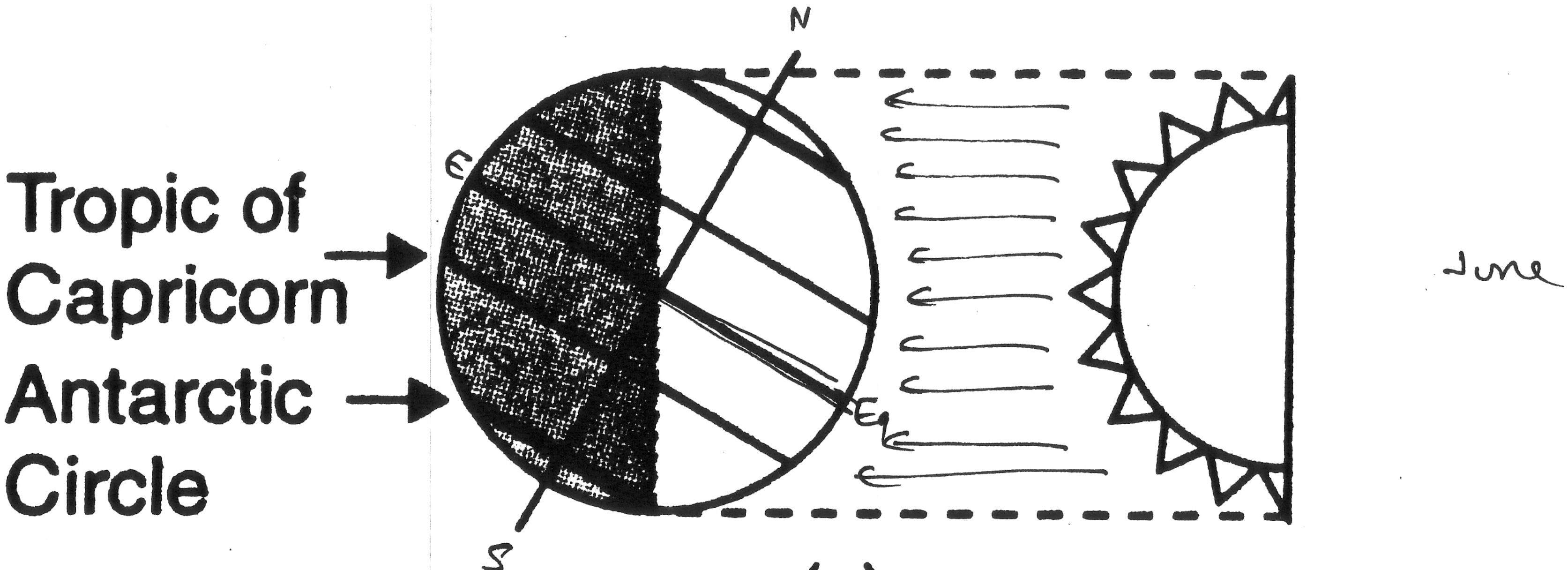
At Seattle, $\alpha = 47.5°$

time	δ	θ	solar radiation
noon 21 June	+23.5	47.5−23.5 = 24°	1324 cos 24 = 1209 W m⁻²
noon 21 Mar, 23 Sep	0	47.5−0 = 47.5°	1370 cos 47.5 = 926 W m⁻²
noon 22 Dec	−23.5	47.5+23.5 = 71°	1418 cos 71 = 462 W m⁻²





(b)



(c)

Hardy Figure 1.4