



MUSTANSIRIYAH UNIVERSITY
COLLEGE OF SCIENCES
DEPARTMENT OF ATMOSPHERIC SCIENCES

DR.HAZIM H. HUSSAIN



Renewable Energy

Welcome Students

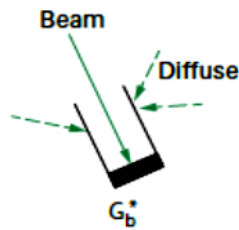
TO LECTURE FOUR



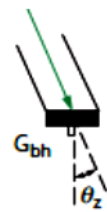
Solar Energy

Components of radiation

Perpendicular to the Sun's beam

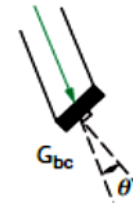


Horizontal



$$G_{bh} = G_b^* \cos \theta_z$$

At the slope of a collector



$$G_{bc} = G_b^* \cos \theta$$

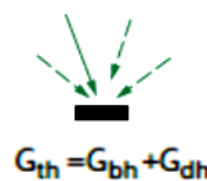
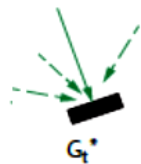
θ is the angle between the beam and the normal to the collector surface.

θ_z is the (solar) zenith angle between the beam and the vertical.

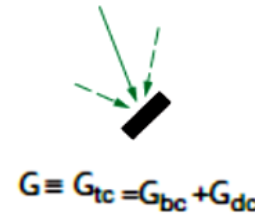
It is important to identify the various components of solar radiation and the plane on which the irradiance is being measured. Let:

- (b) beam,
- (d) diffuse,
- (+) total,
- (h) horizontal plane,
- (c) plane of a collector.

(*) The asterisk denotes the plane perpendicular to the beam.



$$G_{th} = G_{bh} + G_{dh}$$



$$G \equiv G_{tc} = G_{bc} + G_{dc}$$

The total irradiance on any plane is the sum of the beam and diffuse components:

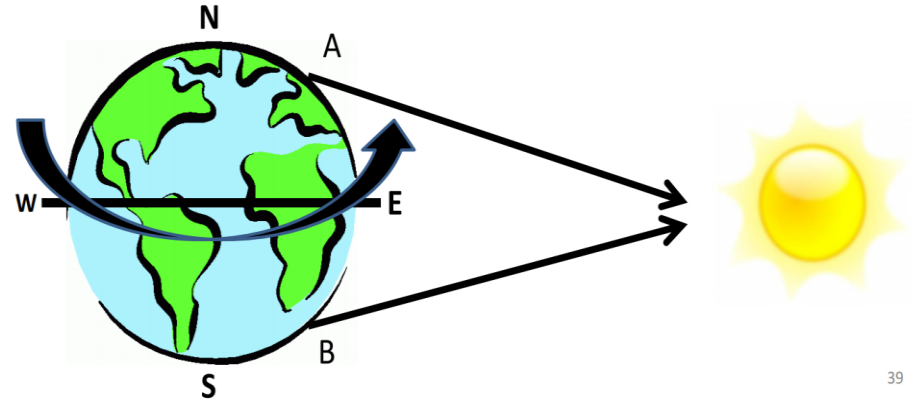
$$G_t = G_b + G_d$$



Solar Energy

Sun position from earth

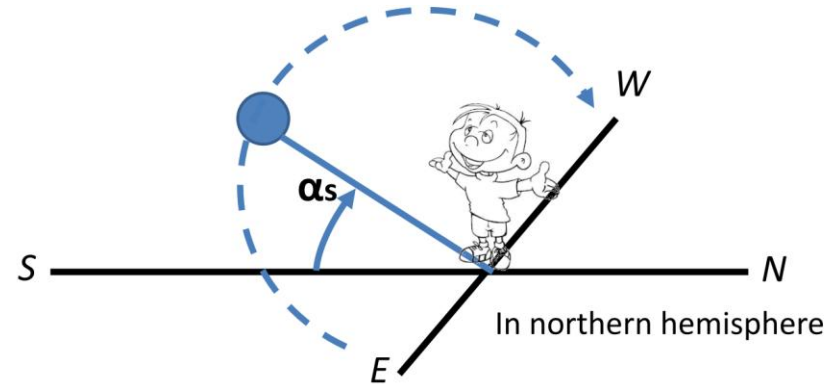
- Sun rise in the east and set in the west
- "A" sees sun in south
- "B" sees sun in north



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Solar altitude angle

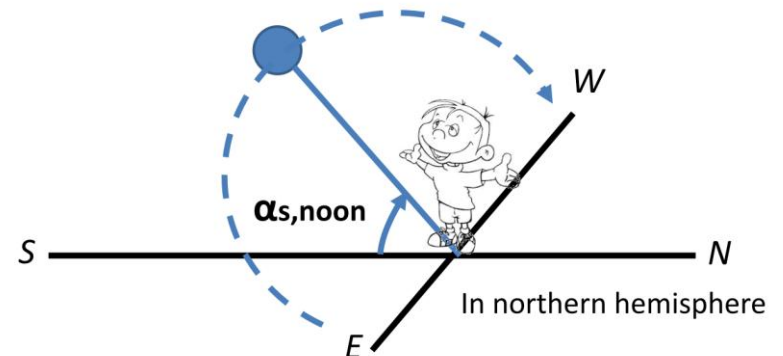
- Solar altitude angle (α_s) is the angle between horizontal and the line passing through sun
- It changes every hour and every day



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Solar altitude angle at noon

- Solar altitude angle is maximum at "Noon" for a day, denoted by $\alpha_{s,noon}$



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Solar Energy

Zenith angle

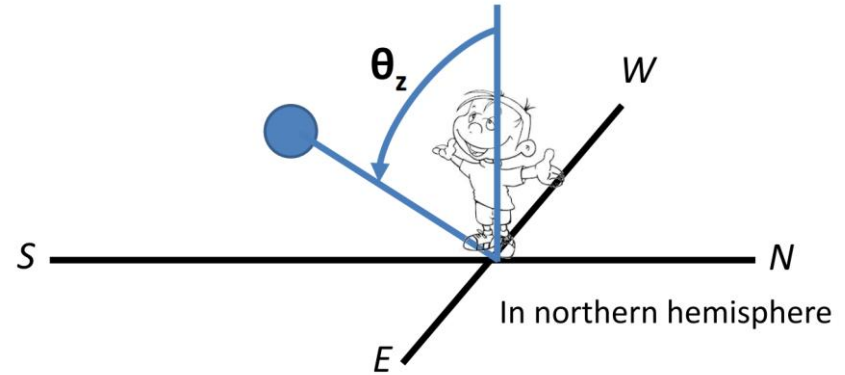
- Zenith angle (θ_z) is the angle between vertical and the line passing through sun
- $\theta_z = 90 - \alpha_s$

Zenith angle at noon

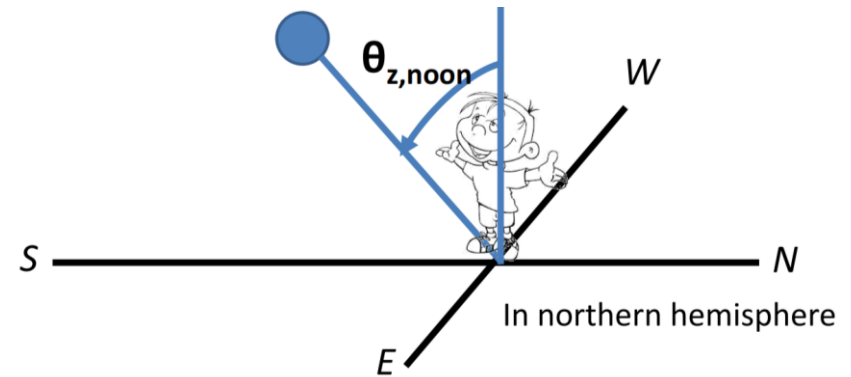
- Zenith angle is minimum at "Noon" for a day, denoted by $\theta_{z,noon}$
- $\theta_{z,noon} = 90 - \alpha_{s,noon}$

Solar azimuth angle

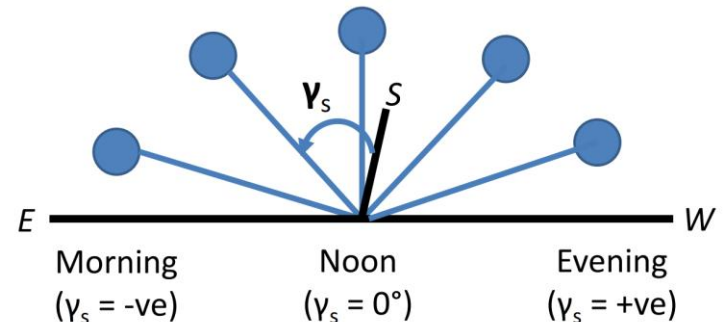
- In any hemisphere, solar azimuth angle (γ_s) is the angular displacement of sun from south
- It is 0° due south, -ve in east, +ve in west



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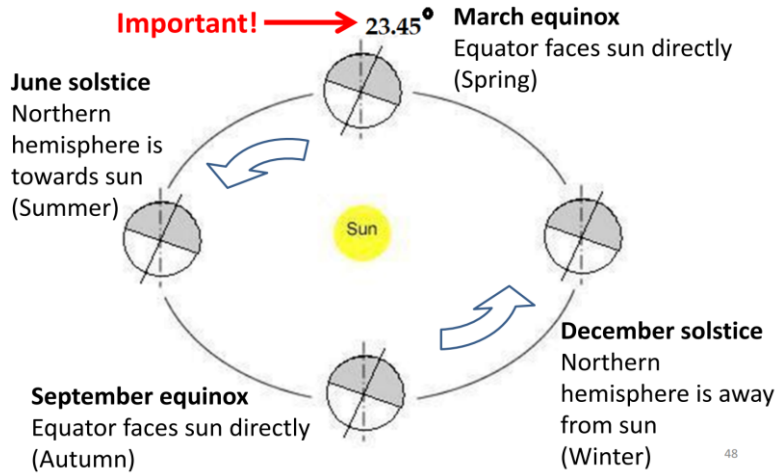


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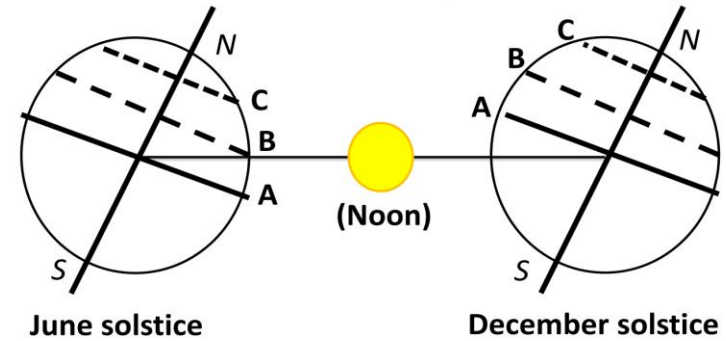


Solar Energy

Solar declination



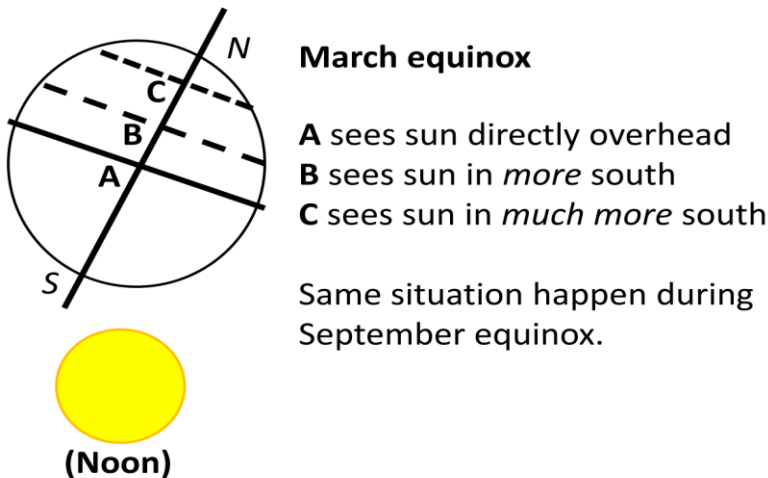
Solar declination (at solstice)



A sees sun in north.
B sees sun overhead.
C sees sun in south.

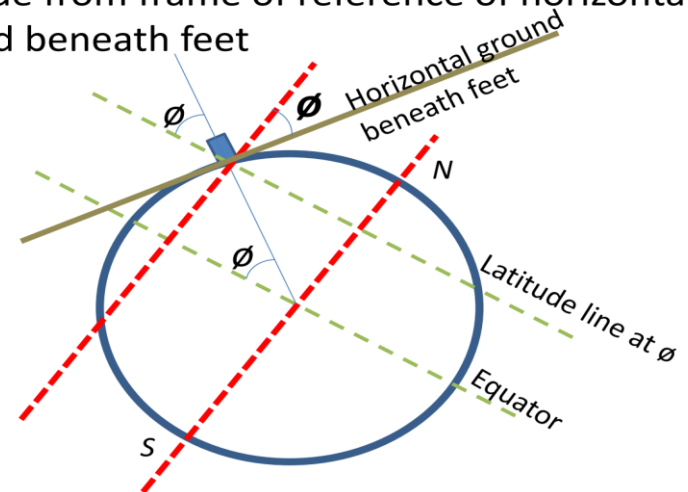
A sees sun in south.
B sees sun in *more* south.
C sees sun in *much more* south.

Solar declination (at equinox)



Solar declination

Latitude from frame of reference of horizontal ground beneath feet





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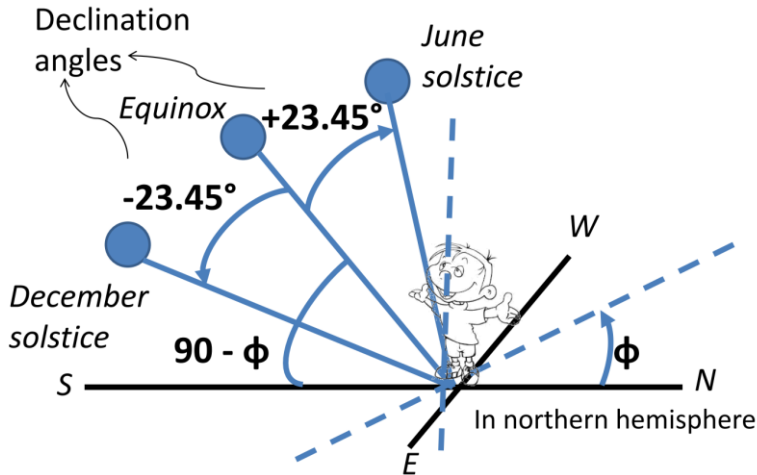
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Solar declination

Solar declination



Note: Altitude depends upon latitude but declination is independent.

Days to Remember	δ
March, 21	0°
June, 21	+23.45°
September, 21	0°
December, 21	-23.45°

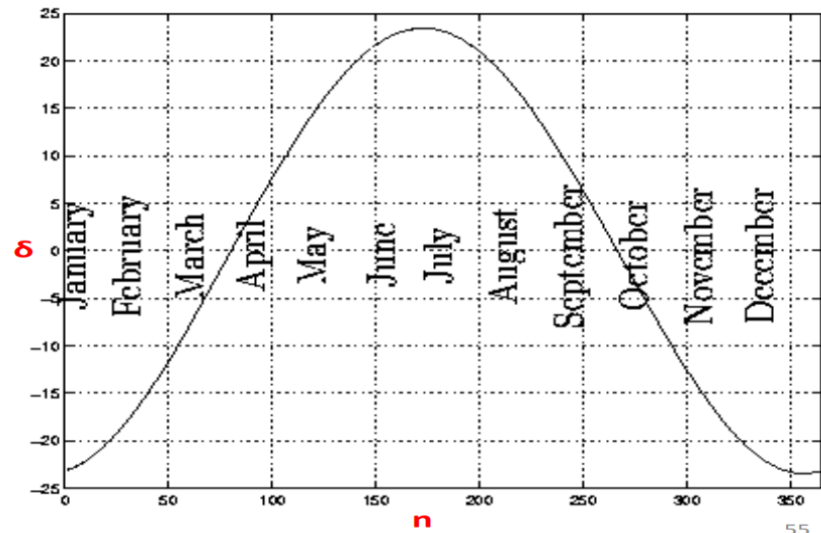
- For any day in year, solar declination (δ) can be calculated as:

$$\delta = 23.45 \sin \left(360 \left(\frac{284 + n}{365} \right) \right)$$

Where, n = numberth day of year

(See "Days in Year" in Reference Information)

- Maximum: 23.45 °, Minimum: -23.45°
- Solar declination angle represents "day"
- It is independent of time and location!





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Solar altitude and zenith at noon

- As solar declination (δ) is the function of day (n) in year, therefore, solar altitude at noon can be calculated as:

$$\alpha_{s,noon} = 90 - \phi + \delta$$

- Similarly zenith angle at noon can be calculated as:

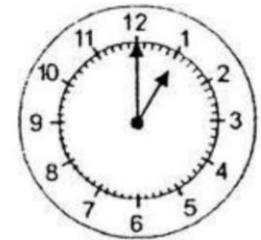
$$\theta_{z,noon} = 90 - \alpha_{s,noon} = 90 - (90 - \phi + \delta) = \phi - \delta$$

Solar time

- The time in your clock (local time) is not same as “solar time”
- It is always “Noon” at 12:00pm *solar time*



Solar time “Noon”



Local time (in your clock)

The difference between solar time (ST) and local time (LT) can be calculated as:

$$ST - LT = E - \frac{4 \times (SL - LL)}{60}$$

Where,

ST: Solar time (in 24 hours format), LT: Local time (in 24 hours format)

SL: Standard longitude (depends upon GMT), LL: Local longitude (+ve for east, -ve for west)

E: Equation of time (in hours)



Solar Energy

- Standard longitude (SL) can be calculated as:

$$SL = (GMT \times 15)$$

Where GMT is Greenwich Mean Time, roughly:

If $LL > 0$ (Eastward):

$$GMT = \text{ceil } LL T15$$

If $LL < 0$ (Westward):

$$GMT = -\text{floor } LL T15$$

GMT for Karachi is 5, GMT for Tehran is 3.5.

It is recommended to find GMT from standard

The term Equation of time (E) is because of earth's tilt and orbit eccentricity.
t can be calculated as:

$$E = \frac{229.2}{60} \times \begin{pmatrix} 0.000075 \\ +0.001868 \cos B \\ -0.032077 \sin B \\ -0.014615 \cos 2B \\ -0.04089 \sin 2B \end{pmatrix}$$

Where,

$$B = (n - 1)360/365$$