SOLAR ENERGY SYSTEMS

B.Tech VI Semester

Mechanical Engineering

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UNIT – I

INTRODUCTION SOLAR RADIATION

Non renewable vs. Renewable

Non renewable Natural resources that can be replaced and reused by nature are termed renewable. Natural resources that cannot be replaced are termed nonrenewable.

renewable vs. Renewable

Renewable resources are replaced through natural processes at a rate that is equal to or greater than the rate at which they are used, and depletion is usually not a worry.

Nonrenewable resources are exhaustible and are extracted faster than the rate at which they formed. E.g. Fossil Fuels (coal, oil, natural gas).

How much longer can we depend on Fossil fuels?

- Because they are fossil fuels they do have a life expectancy.
- Burning fossil fuels has increased atmospheric pollution.
- The carbon stored in fossil fuels is released as carbon dioxide when they are burnt – this leads to the green house effect and global warming.

Sl. No.	Per Capita onsumption (kWh)		
	Name of the Country	2011	2012
1	Canada	16406	15558
2	USA	13227	12947
3	Australia	10514	10218
4	Japan	7847	7753
5	France	7318	7367
6	Germany	7083	7138
7	Korea	10162	10346
8	UK	5518	5452
9	Russia	6533	6602
10	Italy	5393	5277
11	South Africa	4694	4410
12	Brazil	2441	2509
13	China	3298	3475
14	India*	819	884
15	World	2933	2972

	T & D Losses (%)		
Sl. No.	Name of the Country	2011	2012
1	Korea	3.57	3.47
2	Japan	4.98	4.79
3	Germany	4.70	4.46
4	Italy	6.46	6.61
5	Australia	5.94	5.68
6	South Africa	9.61	10.19
7	France	6.47	7.99
8	China	6.54	6.56
9	USA	6.41	6.73
10	Canada	6.27	8.19
11	UK	8.06	8.26
12	Russia	12.59	12.59
13	Brazil	16.08	16.63
14	India	23.97	23.65
15	World	8.90	8.89

Note :-

Basic data obtained from IEA Website (Except India)

* Per Capita Consumption= (Gross Electrical Energy Availability/Midyear Population).

Source wise and state wise estimated potential of renewable power in INDIA as on 31.03.2012

(In MW)

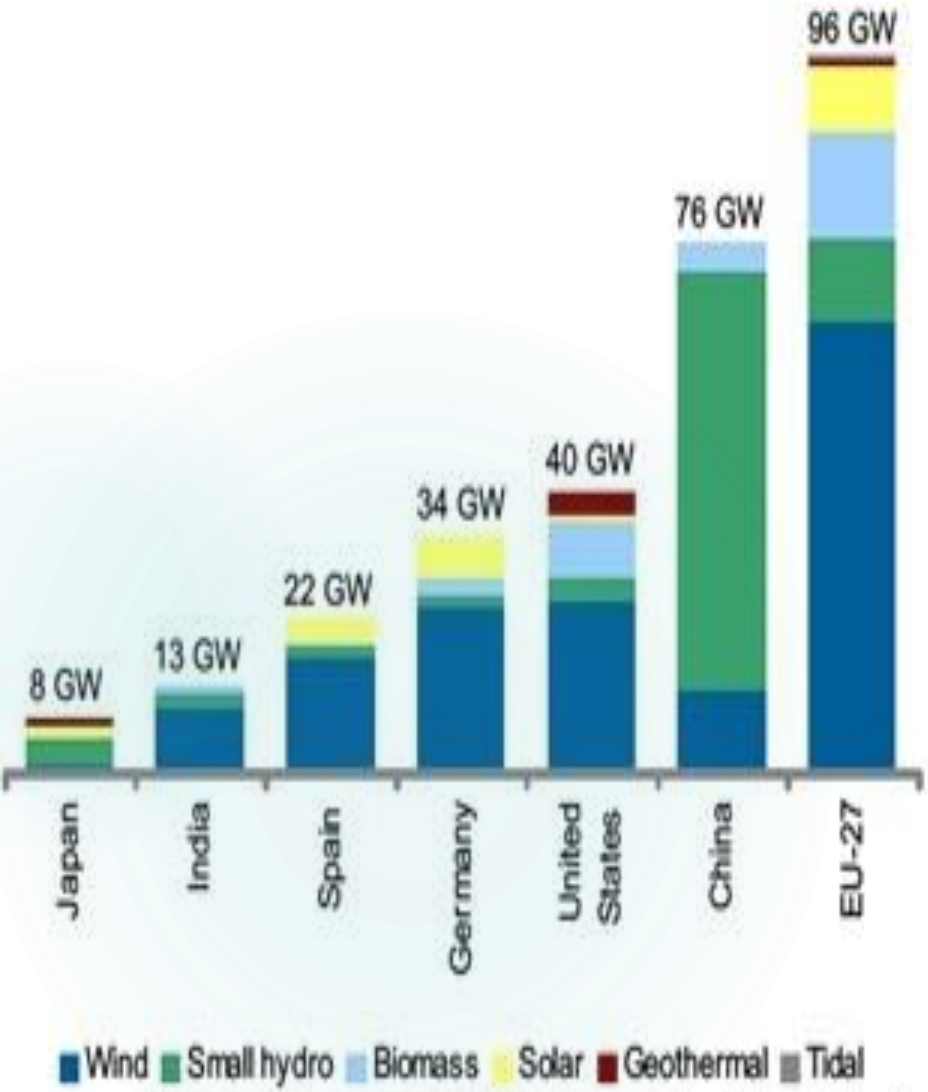
States/ UTs	Wind Power	Small Hydro Power	Biomass Power	Cogeneration-bagasse	Waste to Energy	Total	
						Estimated Reverses	Distribution (%)
1	2	3	4	5	6	7	8
Andhra Pradesh	5394	560	578	300	123	6955	7.75
Arunachal Pradesh	201	1334	8	0	0	1543	1.72
Assam	53	239	212	0	8	512	0.57
Bihar	0	213	619	300	73	1205	1.34
Chhattisgarh	23	993	236	0	24	1276	1.42
Goa	0	7	26	0	0	33	0.04
Gujarat	10609	197	1221	350	112	12489	13.91
Haryana	0	110	1333	350	24	1817	2.02
Himachal Pradesh	20	2268	142	0	2	2432	2.71
Jammu & Kashmir	5311	1418	43	0	0	6772	7.54
Jharkhand	0	209	90	0	10	309	0.34
Karnataka	8591	748	1131	450	151	11071	12.33
Kerala	790	704	1044	0	36	2574	2.87
Madhya Pradesh	920	804	1364	0	78	3166	3.53
Maharashtra	5439	733	1887	1250	287	9596	10.69
Manipur	7	109	13	0	2	131	0.15
Meghalaya	44	230	11	0	2	287	0.32
Mizoram	0	167	1	0	2	170	0.19
Nagaland	3	197	10	0	0	210	0.23
Odisha	910	295	246	0	22	1473	1.64
Punjab	0	393	3172	300	45	3910	4.36
Rajasthan	5005	57	1039	0	62	6163	6.87
Sikkim	98	266	2	0	0	366	0.41
Tamil Nadu	5374	660	1070	450	151	7705	8.58
Tripura	0	47	3	0	2	52	0.06
Uttar Pradesh	137	461	1617	1250	176	3641	4.06
Uttaranchal	161	1577	24	0	5	1767	1.97
West Bengal	22	396	396	0	148	962	1.07
Andaman & Nicobar	2	7	0	0	0	9	0.01
Chandigarh	0	0	0	0	6	6	0.01
Dadar & Nagar Have	0	0	0	0	0	0	0.00
Daman & Diu	0	0	0	0	0	0	0.00
Delhi	0	0	0	0	131	131	0.15
Lakshadweep	16	0	0	0	0	16	0.02
Puducherry	0	0	0	0	3	3	0.00
Others*	0	0	0	0	1022	1022	1.14
All India Total	**49130**	**15399**	**17538**	**5000**	**2707**	**89774**	**100.00**
Distribution (%)	**54.73**	**17.15**	**19.54**	**5.57**	**3.02**	**100.00**	

* Industrial waste
Source: Ministry of New and Renewable Energy

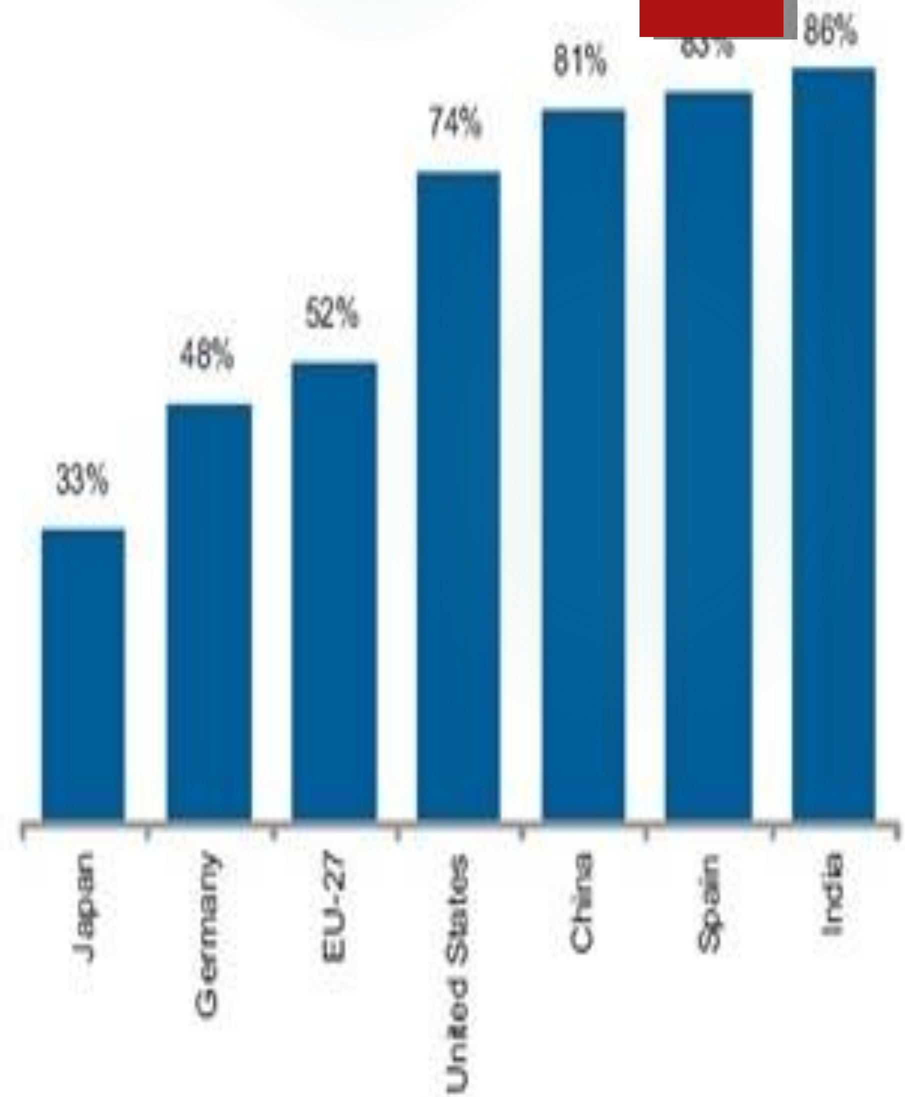
Power production status of non-conventional energy in India

Renewable Power	Potential	Achieved
Wind Power	20,000 MW	1,000 MW
Small Hydro Power	10,000 MW	172 MW
Biomass	20,000 MW	141 MW
Solar photo-voltic Power	20 MW/sq.km	810 KW

Renewable Electric Power Capacity (GW) Existing as of 2008



% Increase in Renewable Electric Pow city from 2005 – 2008



Source: DBCCA analysis, 2010; REN21, "Renewables Global Status Report," 2006 and 2009.

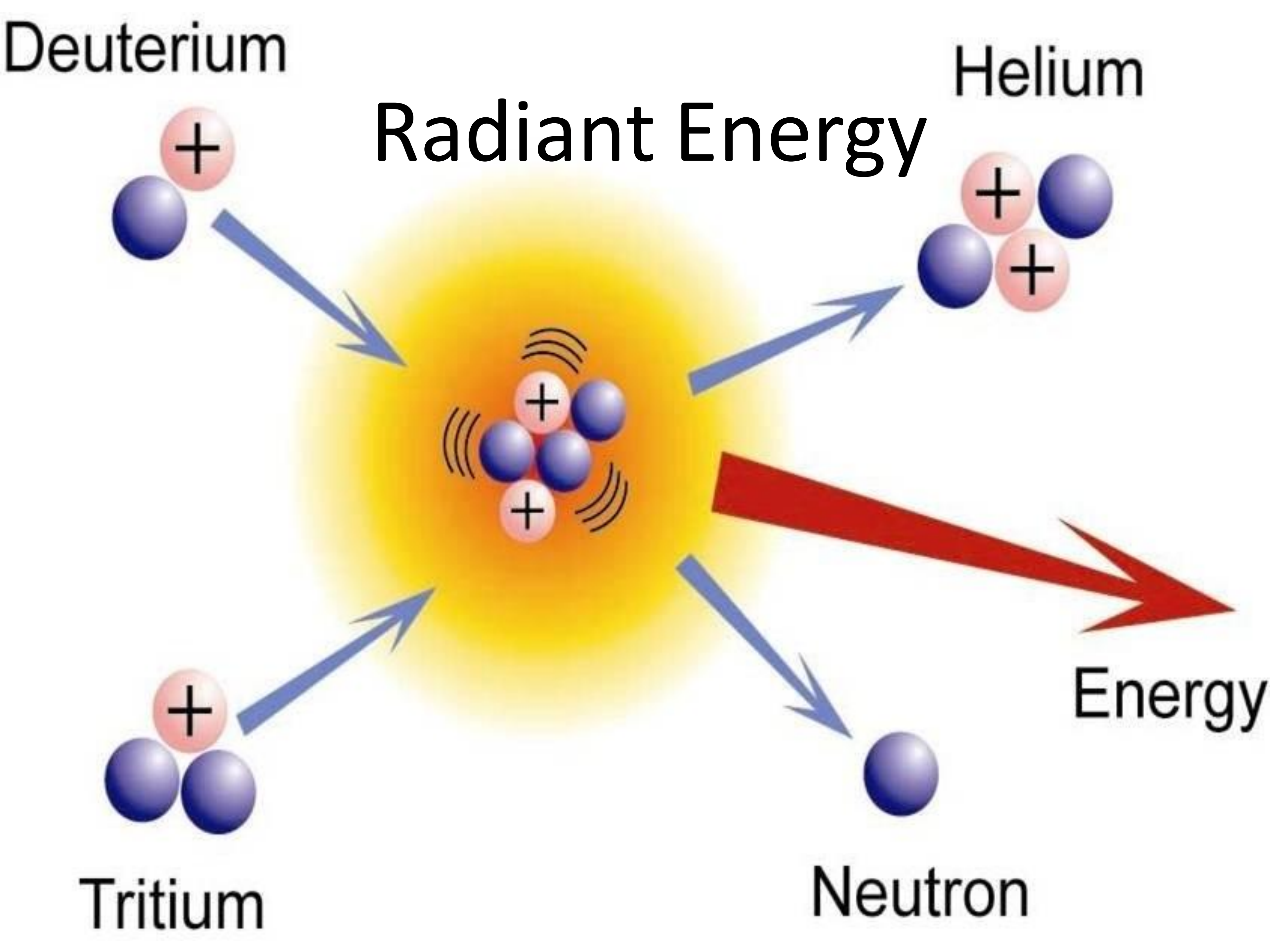
Renewable energy scenario in India

Government created the Department of Non-conventional Energy Sources (DNES) in 1982. In 1992 a full fledged Ministry of Non- conventional Energy Sources was established under the overall charge of the Prime Minister.
The range of its activities cover

1. Promotion of renewable energy technologies,
2. Create an environment conducive to promote renewable energy technologies,

3.Create an environment conducive for their commercialization,
4.Renewable energy resource assessment,
5.Research and development,
6.Demonstration,
7.Production of biogas units, solar thermal devices, solar photovoltaics, cookstoves, wind energy and small hydropower units.

Radiant Energy

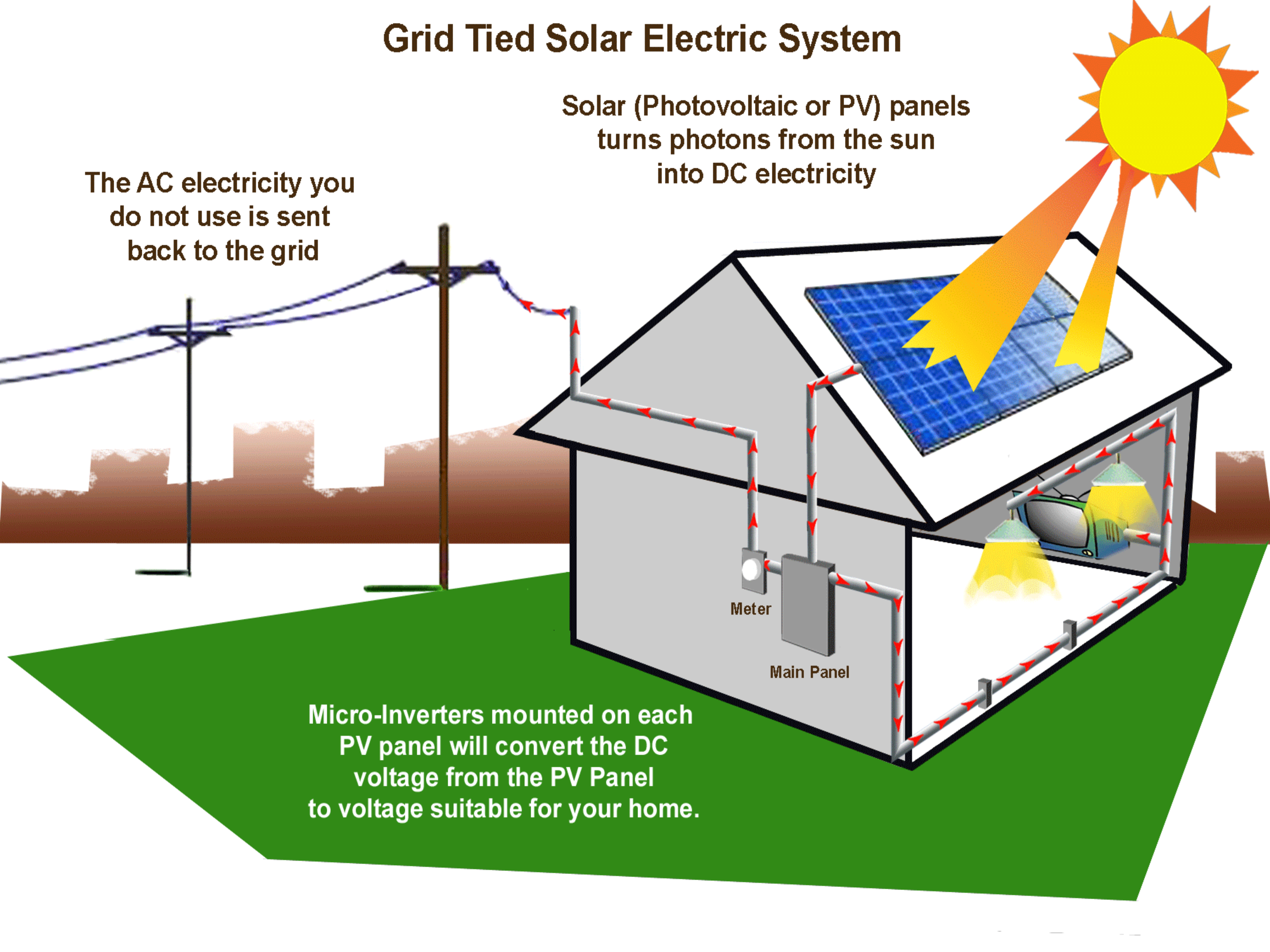


Major uses of Solar Energy

- Heating Water
- Space Heating
- Generating Electrical Energy

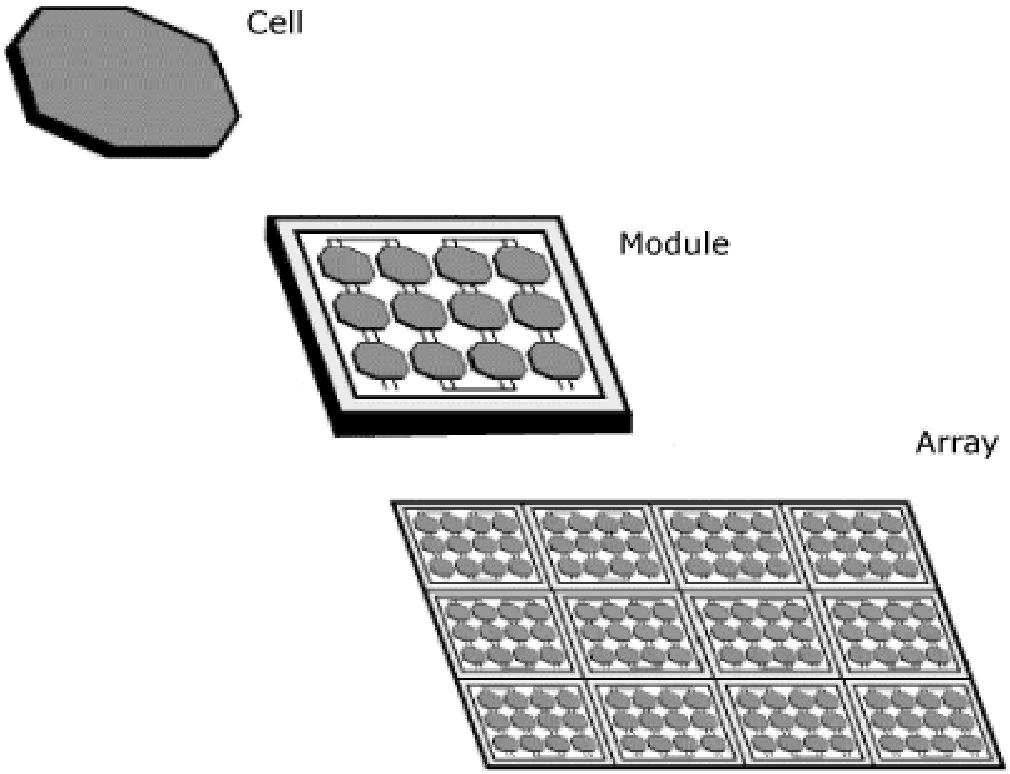
Solar Technologies

- Day lighting
- Passive Solar Heating
- Concentrating Solar Thermal
- Photovoltaic (PV)


Grid Tied Solar Electric System
Solar (Photovoltaic or PV) panels turns photons from the sun into DC electricity
The AC electricity you do not use is sent back to the grid
Meter
Main Panel
Micro-Inverters mounted on each PV panel will convert the DC voltage from the PV Panel to voltage suitable for your home.

Photovoltaic Components

- PV Cells
- Modules
- Arrays



Advantages of Solar Energy

- Clean
- Sustainable (can be used for longer duration)
- Free of cost
- Provide Electricity to Remote Places

Disadvantages of Solar Energy

- Inefficient – maximum efficiency up to 30%.
- Costly equipment.
- Part Time.
- High maintenance cost.

Photovoltaic Array Fields

Photovoltaic Array Fields

INDIA
Solar Power Projects
N
AFGHANISTAN
PAKISTAN
CHINA
(Tibet)
NEPAL
BHUTAN
BANGLADESH
MYANMAR
Muktsar
Chandigarh
Aligarh
Lucknow
Munath Bhanjan
Rajgarh
Dewas
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ARABIAN SEA
BAY OF BENGAL
Bengaluru
Chennai
Coimbatore
Tiruchirapalli
LAKSHADWEEP (INDIA)
ANDAMAN AND NICOBAR ISLANDS (INDIA)
SRI LANKA
INDIAN OCEAN
LEGEND
Solar Power Projects
Map not to Scale
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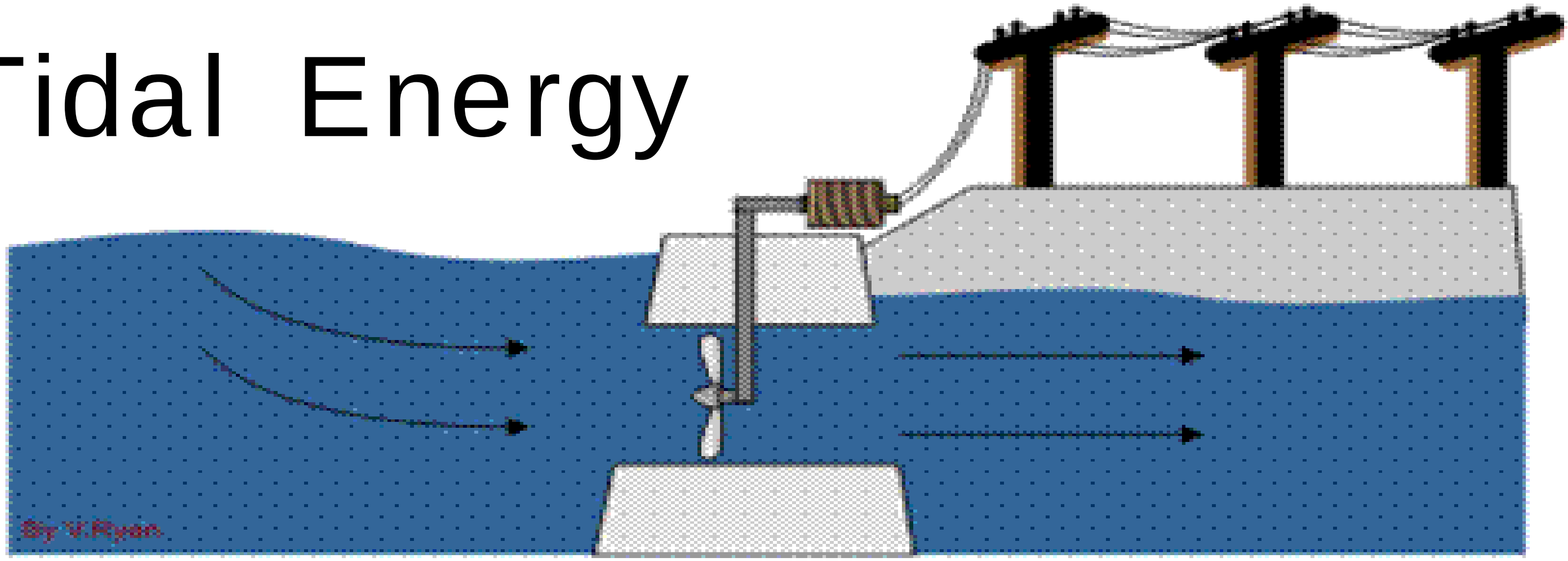
UNIT-II

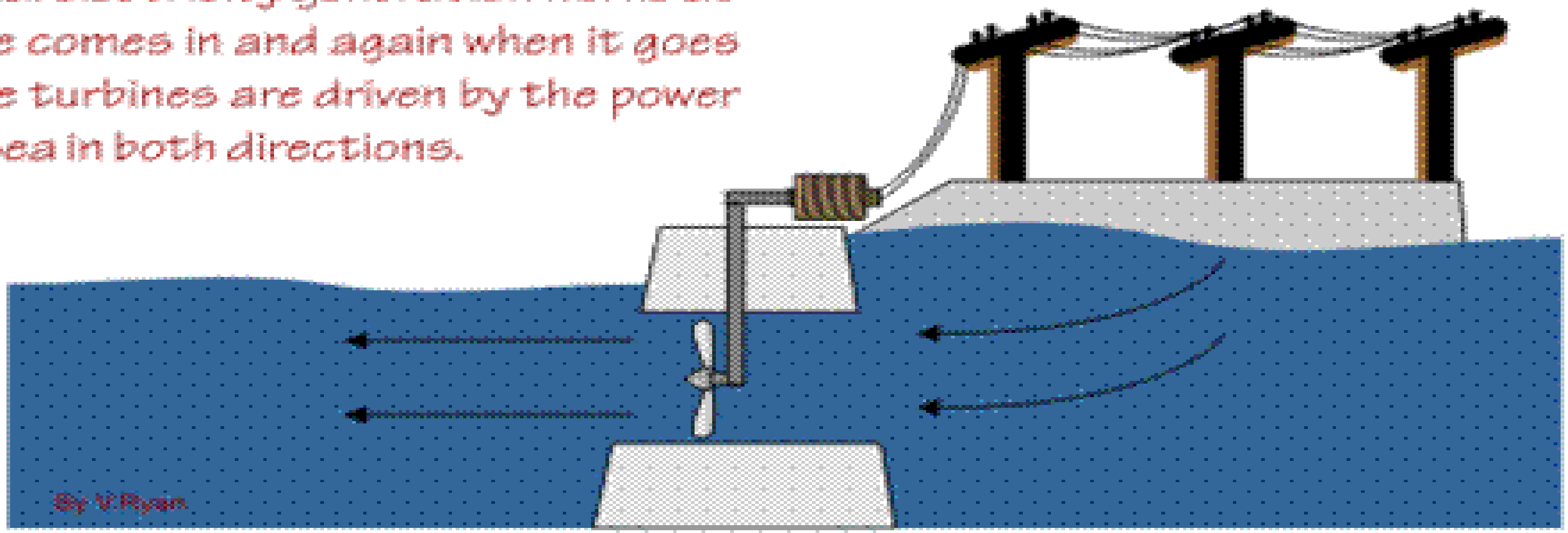
SOLAR ENERGY COLLECTION

Tidal Energy



TIDE COMING IN

This tidal electricity generation works as the tide comes in and again when it goes out. The turbines are driven by the power of the sea in both directions.



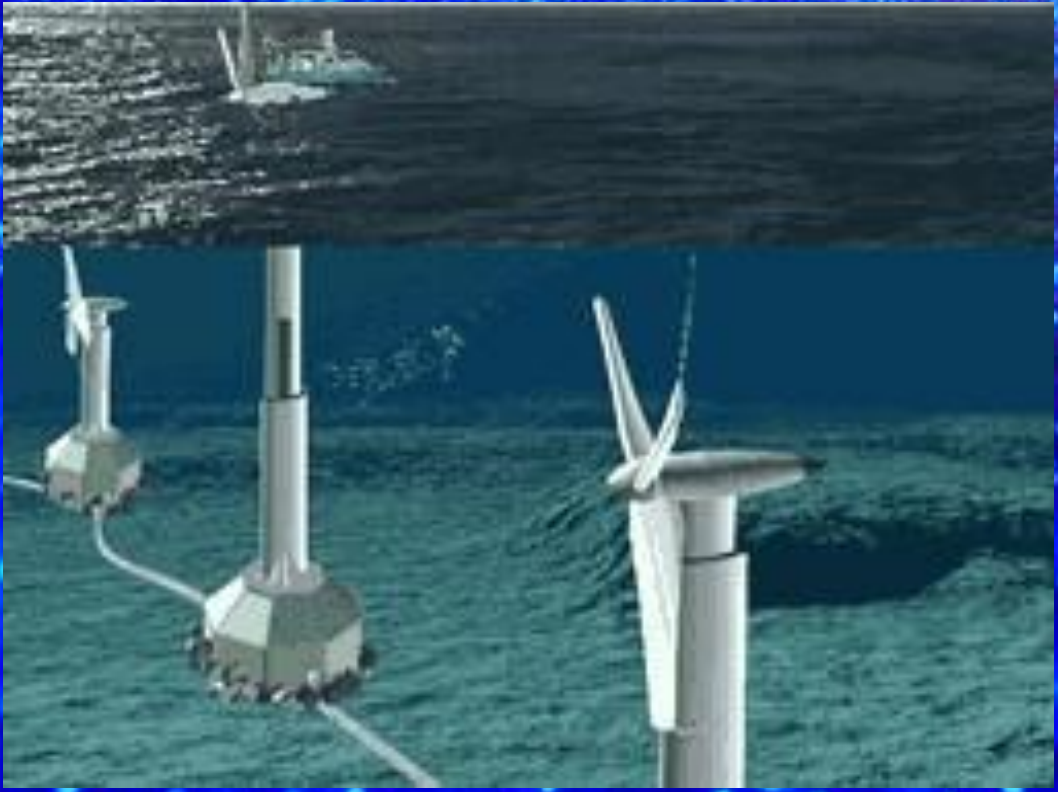
TIDE GOING OUT

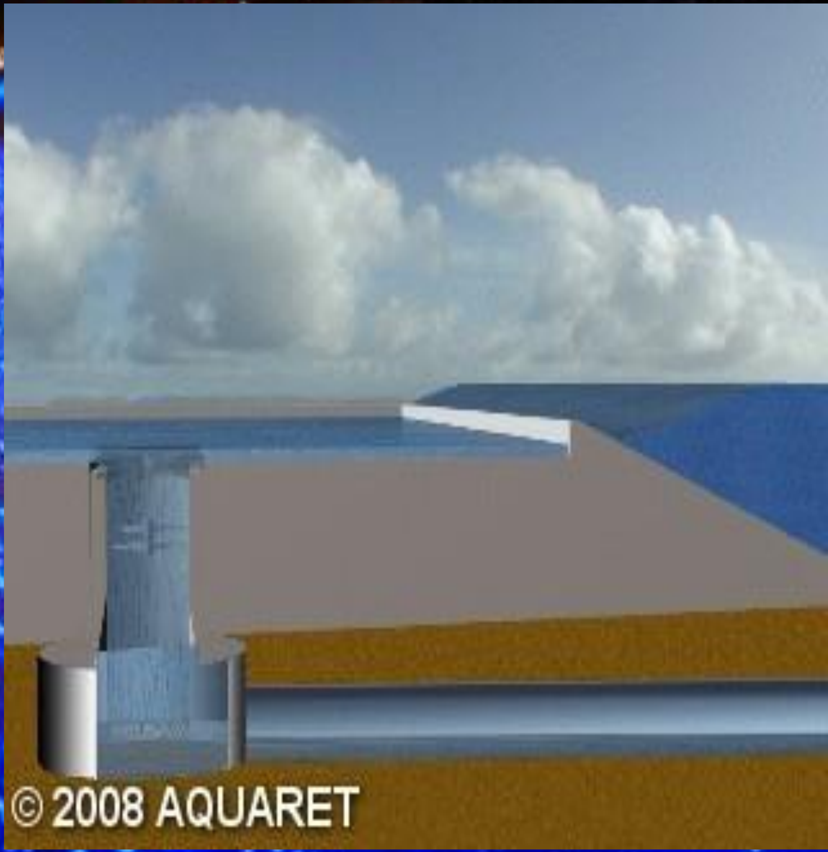
Tidal Energy

Millions of gallons of water flow onto shore during tidal flows and away from shore during ebb (move away from the land)
tide periods.

The larger the tidal influence, the greater the displacement of water and therefore the more potential energy that can be harvested during power generation.

- Tidal energy is one of many formsof hydropower generation.
- Tidal power has many advantages as compared to other forms of renewable energy.
  - It is predictable
  - Global Climate Change should only increase its generating capacity due to higher ocean levels.
  - It is completely carbon neutral like wind or hydro energy.

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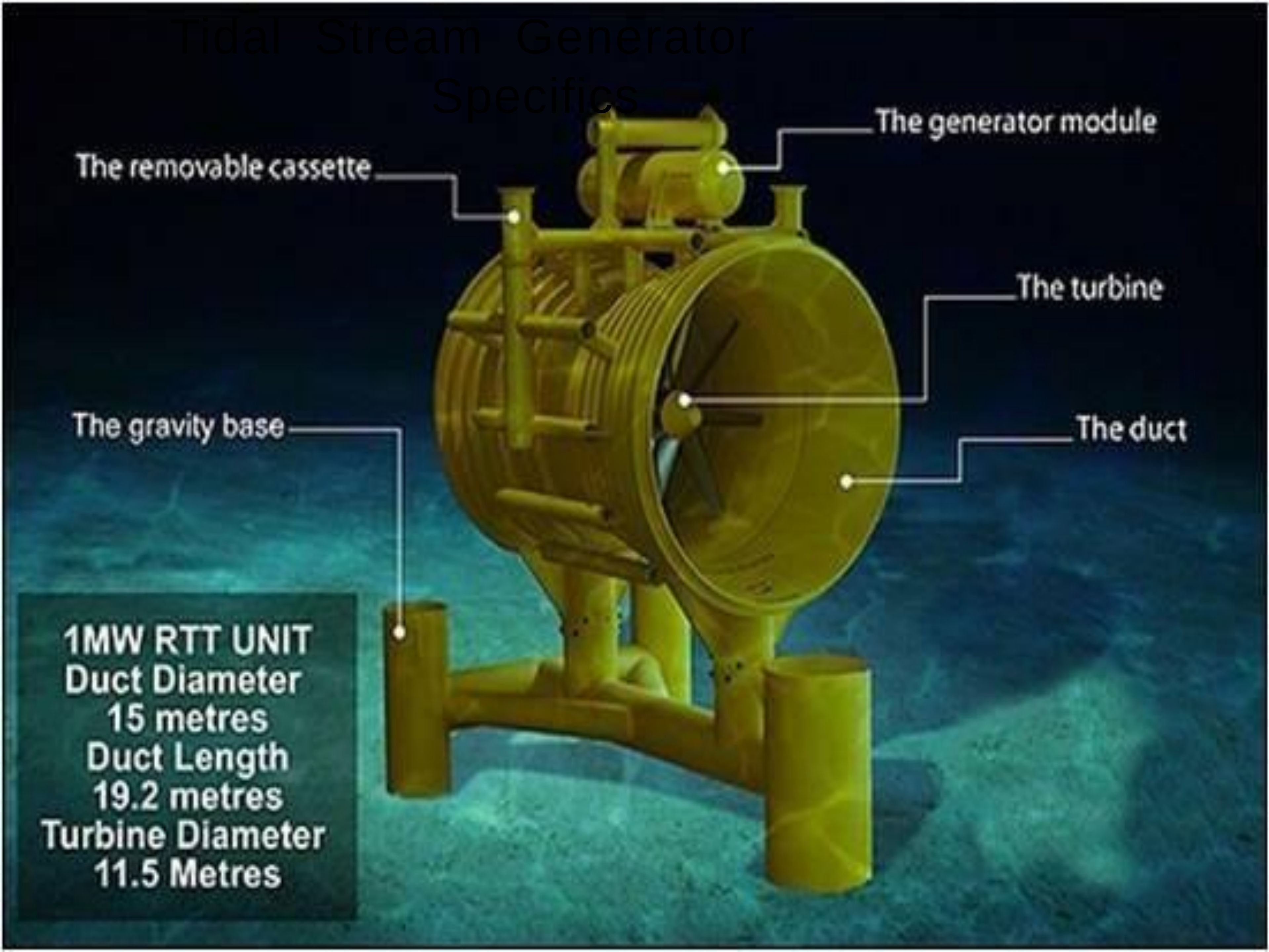
Tidal Stream Generators

The world's only operational commercial-scale tidal turbine, SeaGen, was installed in Strangford Narrows in Northern Ireland in 2008.

The prototype SeaGen turbine produces 1.2MW with currents of 2.4m/s or more. The capacity factor exceeds 60%.

The facility is an accredited UK power station, and can contribute up to 6,000MWh annually to the UK grid, the equivalent of approximately 1500 homes.

Tidal Stream Generator Specifics



Advantages of using Tidal Power

- Predictable source of “green" energy during lifetime of barrage
- It produces no greenhouse gases or other waste; it needs no fuel.
- Not expensive to maintain.
- Tidal energy has an efficiency of 80% in converting the potential energy of the water into electricity
- Vertical-axis tidal generators may be joined together in series to create a ‘tidal fence’ capable of generating electricity on a scale comparable to the largest existing fossil fuel based, hydroelectric and nuclear energy generation facilities

Disadvantages of using Tidal Power

- A barrage across an estuary is very expensive to build, and affects a very wide area – the environment is changed for many miles upstream and downstream.
- It provides power for around 10 hours each day, when the tide is actually moving in or out, which is not very much
- Existing ecosystems would be heavily altered, with new species moving in and perhaps dominating old species.
- Tidal power schemes have a high capital cost.

Environmental Effects

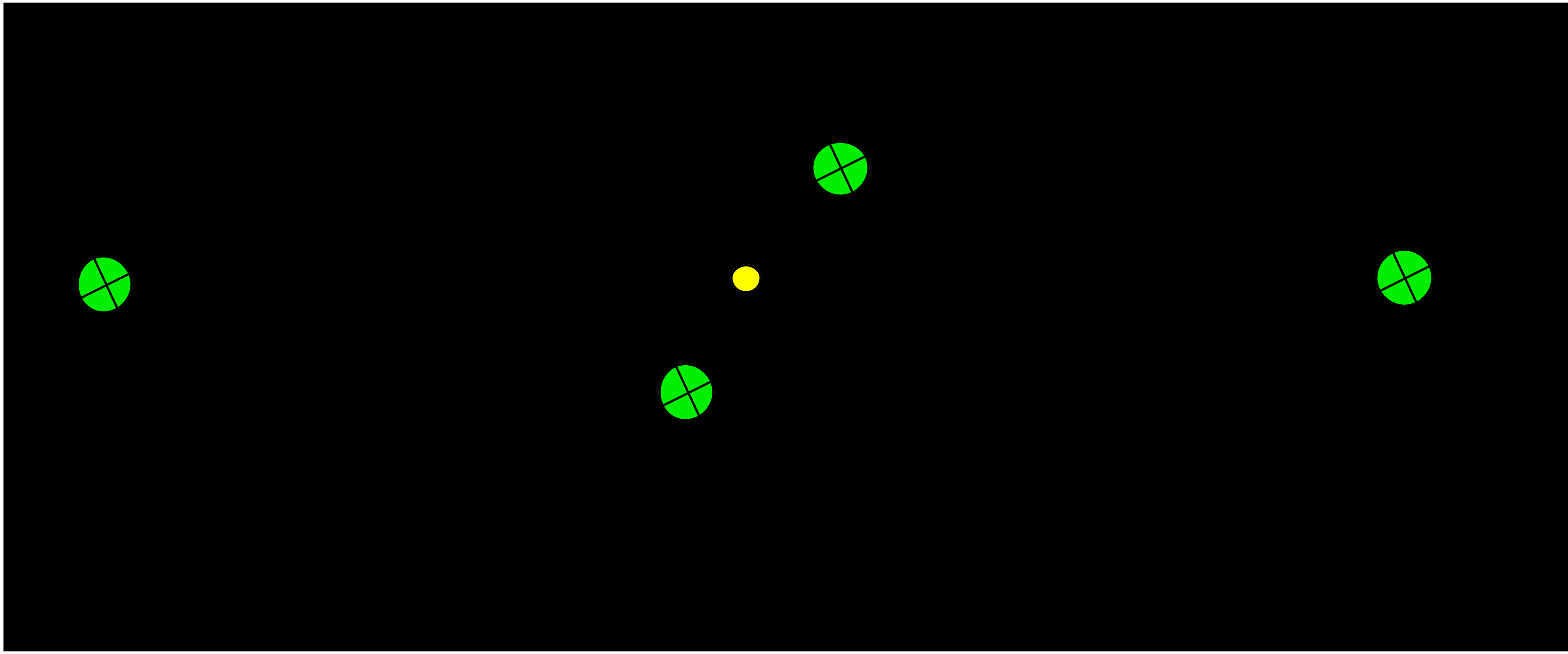
- A tidal power scheme is a long-term source of electricity. A proposal for the Severn Barrage, if built, has been projected to save 18 million tones of coal per year of operation. This decreases the output of greenhouse gases into the atmosphere.

- If fossil fuel resource is likely to decline during the 21st century, as predicted by Hubbert peak theory, tidal power is one of the alternative source of energy that will need to be developed to satisfy the human demand for energy.

- Motion of the Earth and Sun
  - Geometry of Earth/Sun system
  - Astronomical coordinates
  - Motion of the Earth around the sun
  - Equation of Time
- Astronomical positioning
  - Latitude and Longitude determination using astronomical bodies
- Error contributions to latitude and longitude measurements.

Geometry of Earth Sun System

- Figure below shows the basic geometry



Geometry of Earth Sun

- The Earth's equator plane is inclined at ~23.5^o to the orbit plane (called the ecliptic)
- It takes ~365.25 solar days for one orbit (hence a leap-year every 4 years, and the odd rule about leap years at century boundaries because the value is not exactly 365.25 solar days.
- A solar-day is the length of time (on average) for the sun to move from noon to noon. Because the earth moves in its orbit by a little during the day, the length of time for stars to come to the same place in the sky is a little bit shorter.
- A sidereal-day is the length of time for stars to come back to the same point in the sky
- There are ~366.25 sidereal days in a year (the extra day is basically one rotation due to the orbit in one year).

Time systems

- There are a number of time systems encountered in astronomy and navigation.
- Time keep by our watches is related to Universal Time Coordinated (UTC). Used to be called Greenwich Mean Time (GMT)
  - UTC is based on atomic time standards (Cesium clocks) and is an average over Cesium clocks operated all around the world. The US clocks are operated at the US Naval Observatory in Washington DC
  - The International Earth Rotation Service (IERS) (and formally the Bureau International de Le Heure (BIH)) coordinates these activities and publishes corrections to the time systems operated in each country

Time systems

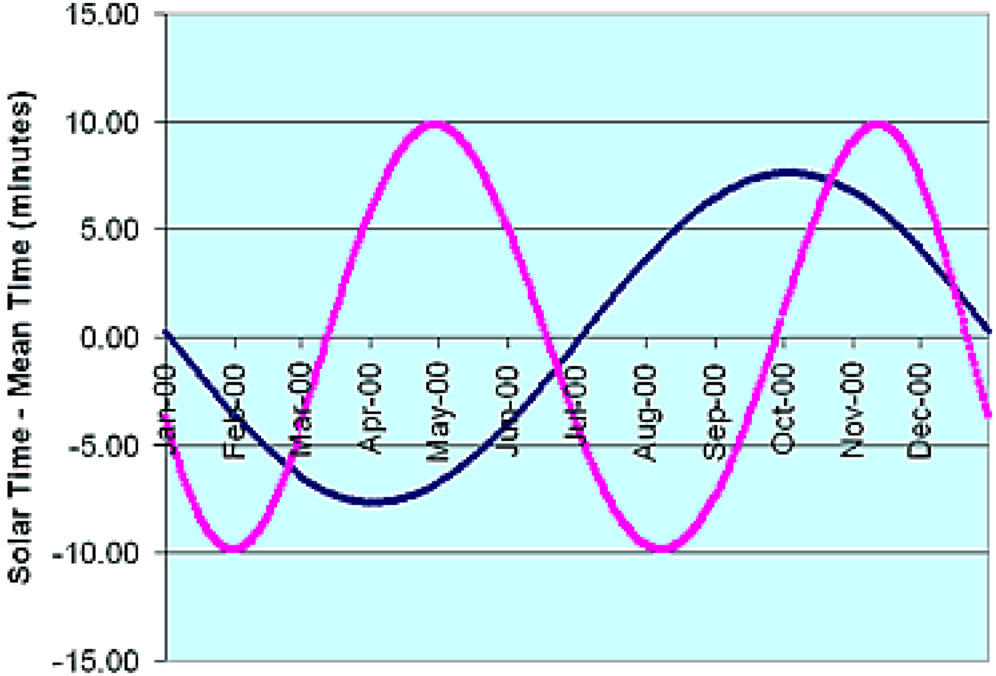
- The time defined by atomic clocks runs at a constant rate. Unfortunately, we tend to perceive time by the rotation of the Earth which is not uniform. There is a slowing of the rate of rotation of Earth (about 1 second every 18 months) and there are fluctuations due mainly to changes in atmospheric winds and processes in the fluid core.
- Time defined by the rotation of the Earth is called UT1 and is solar day system.
- UTC has discontinuities, call leap-seconds, that are added to keep it aligned with UT1. (When the atomic second was adopted in the mid-1950s the rates were the same and so leap-seconds were not needed. They were introduced in the mid-1960s after the Earth rotation rate had slowed enough that the difference between UT1 and UTC had reached several seconds.

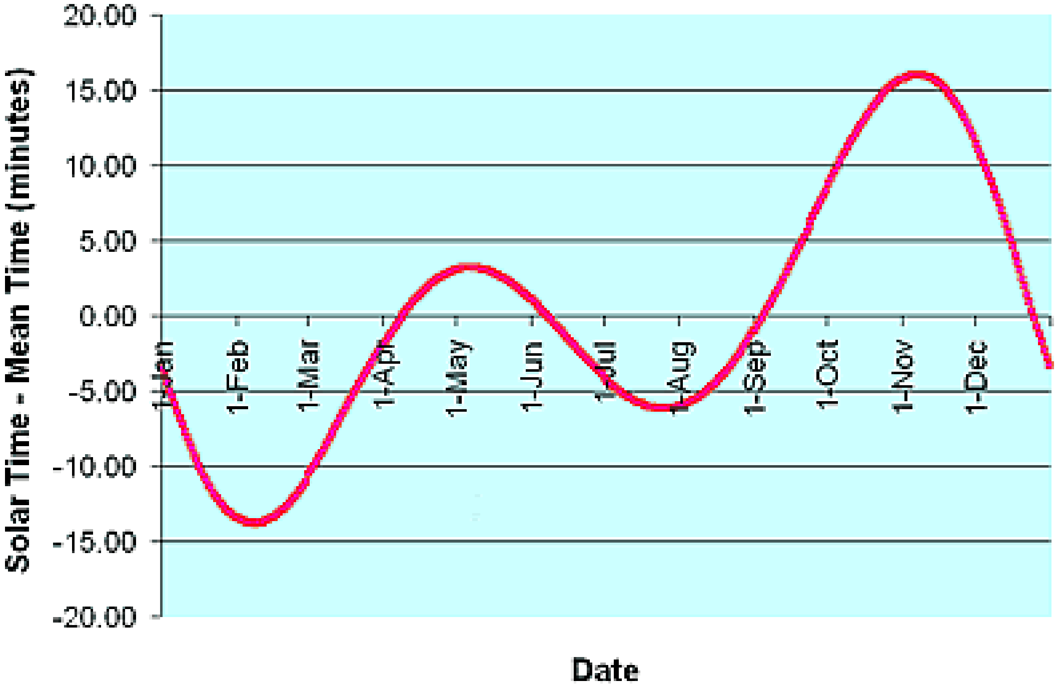
Time systems

- The difference between UT1 and UTC has be measured and the IERS coordinates these measurements and published differences between UT1 and UTC. (They also decide when leap seconds need to be added).
- Sidereal time is derived from UT1 and measures times in sidereal seconds. If we ran our watches on sidereal time, the stars would also be in the same place in the sky at the same time. (With solar time, the stars rise 4 minutes earlier each night).

Solar time

- Solar time is based on the mean solar day, but the time that Sun reaches its highest point each day (around noon) varies through out the year. The difference between noon at Greenwich and when the sun is at its highest point (or highest elevation angle) is call the Equation of Time.
- There are two components to the equation:
  - The Earth's orbit is eccentric (e=0.0167) and so moves at different speeds through the orbit, causes an annual variation.
  - The equator is included to the orbit plane (obliquity of the ecliptic) by ~23.5^{o} and this causes a semi-annual variation.
  - Combination of the two effects cause changes in the time of noon at Greenwich by -14 to +16 minutes (see URL:





Equation of Time

Graphics from URL given on previous page

For Longitude determination using the sun, this effect must be accounted for (15 minutes of time~225 nautical miles)

Astronomical position determination

- To determine position using astronomical measurements (or a sextant) requires relating positions of celestial objects to Earth coordinates.
- Celestial coordinates:
  - Declination: Measured from equator and it astronomical coordinate equivalent to latitude
  - Right Ascension: Angle measured along the equator (similar to longitude) but origin is the intersection of the equator and ecliptic planes (called the first point of Aries).
- Celestial coordinates are specified in a non-rotating or slowly rotating frame. The diurnal rotation of the Earth is not in the coordinates.

Celestial coordinates

- Since the celestial coordinates are given in a system attached to the equator of the Earth, they would change slowly with time due to precession (26,000 year motion of the rotation axis, about an axis perpendicular to the orbit plane), and notation (nodding of the rotation axis in space due to gravitational torque on the equatorial bulge.
- Because of these motions of the rotation axis (and hence in the equator) in space, celestial coordinates are generated in a number of systems.

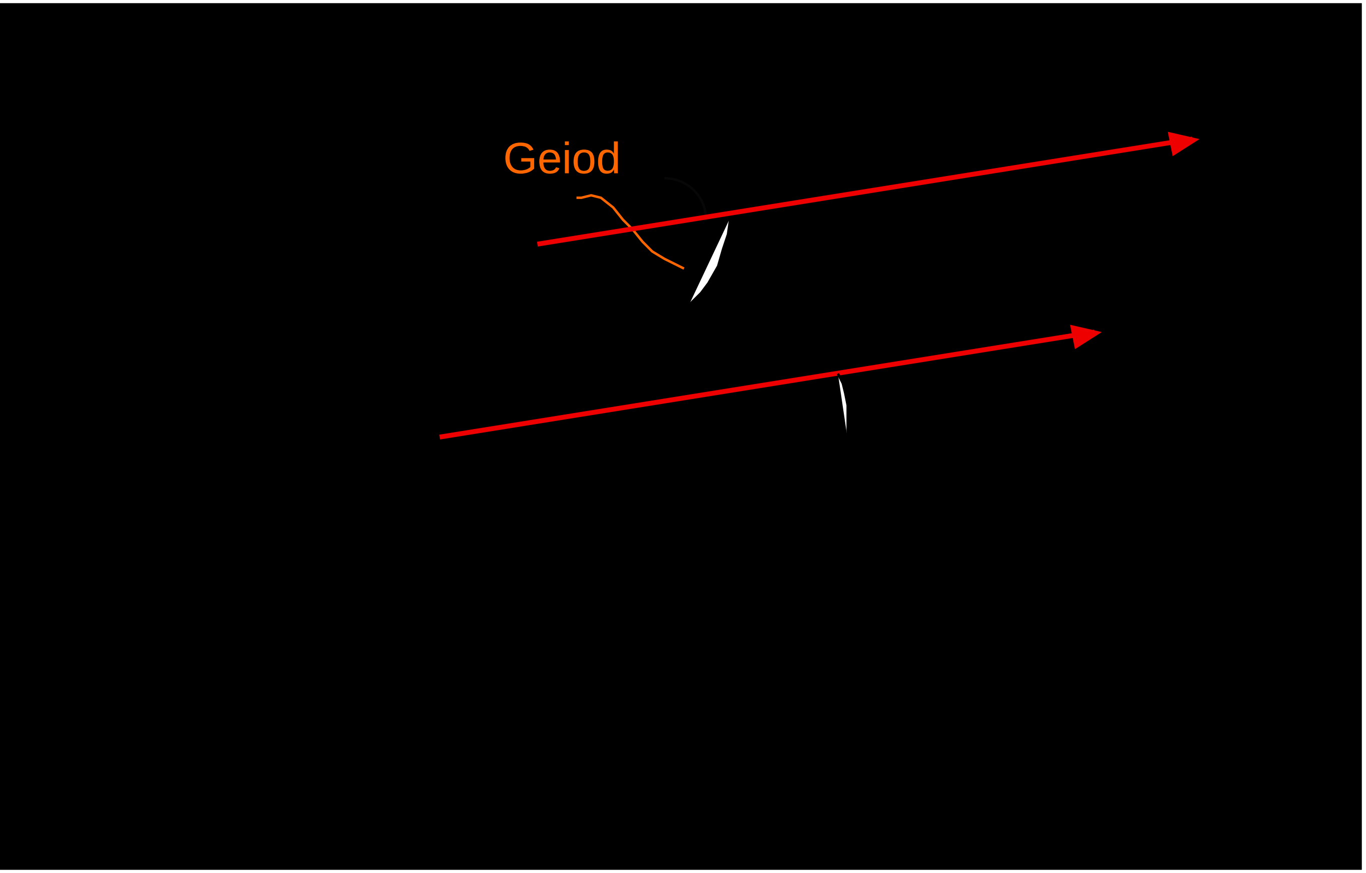
Celestial coordinates

- Fundamental coordinates of stars are given in a system which corresponds to the equator and ecliptic orientations at a specific time, call coordinates of epoch. Current system is call J2000 and is the position at Jan 1.5, 2000.
- The other common system is the coordinates of date corresponding to the equator and ecliptic orientations at the day of interest.
- There is a mathematical relationship through the application of a series of rotation matrices, that allow the systems to be related.
- For navigation, positions of date are used and these can be found in almanacs (or can be computed).

Celestial positioning

- The easiest method for determining latitude and longitude is to make measurements of the elevation angle to the Sun at its highest point and to note the time at which this event occurs. This method requires access to accurate time which was the major advance made in determining longitude by the Harrison clocks.
  The book Longitude details these developments
- To determine latitude, the declination of the sun needs to be known on the day (obtained from almanacs) and the elevation measured (usually over a period of time so that highest point reached can be determined).

Latitude determination



When the sun is at the highest elevation, it is in the plane of the meridian and

ϕ_a=90-e+δ

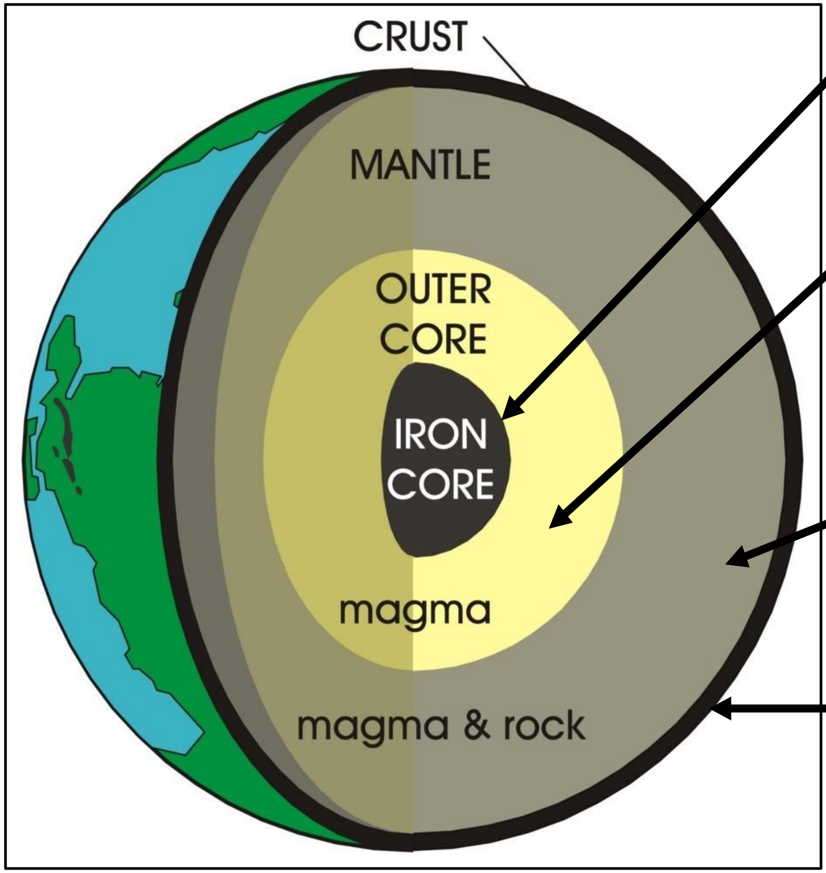
Longitude determination

- The Greenwich observatory publishes tables of the time that the sun will cross the meridian in Greenwich (equation of time) and the difference between the time of the meridian crossing of the Sun at your location and the time in Greenwich, is the longitude of your location in time units. (Multiple by 15 to get degrees).
- Your time has to be converted to UTC which means that the time zone needs to be known (Boston for example is 5 hours from Greenwich except when daylight savings time is in effect and then it is 4 hours).

Errors in positioning

- Several types of errors can effect latitude and longitude determination
- For latitude:
  - Atmospheric bending of the light from the Sun can cause errors of several minutes of arc (several nautical miles). There are approximate equations that allow this to be corrected.
  - There are other errors associated with sextant measurements which we will discuss when we use the instrument
- For longitude:
  - Judging when the sun is at its highest point is difficult because the elevation angle changes slowly at the time
  - Error in knowledge of local time is a large error especially id no external calibration is possible (e.g., when clocks were first used).

The Earth Is Made of Layers



At the center is a **core** of molten iron.

Around that is an outer core of iron and rock so hot that rock is in molted state.

The liquid rock is called **magma** .

The next layer is a mixture of rock and magma called the **mantle** .

The shell of the earth – with the oceans and mountains - is called the **crust** .

EARTH'S ROTATION AND REVOLUTION

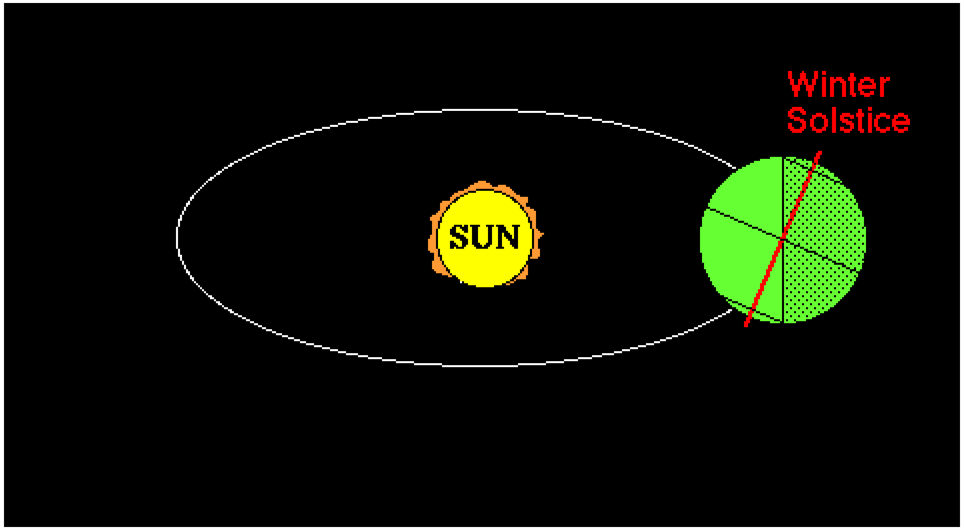
Earth’s Rotation

- Rotation is the spinning of the Earth on its axis.
- The time for one rotation is 24 hours.
- The speed of rotation 24,855 miles/24 hr or 1,038 miles/hr

Earth’s Revolution

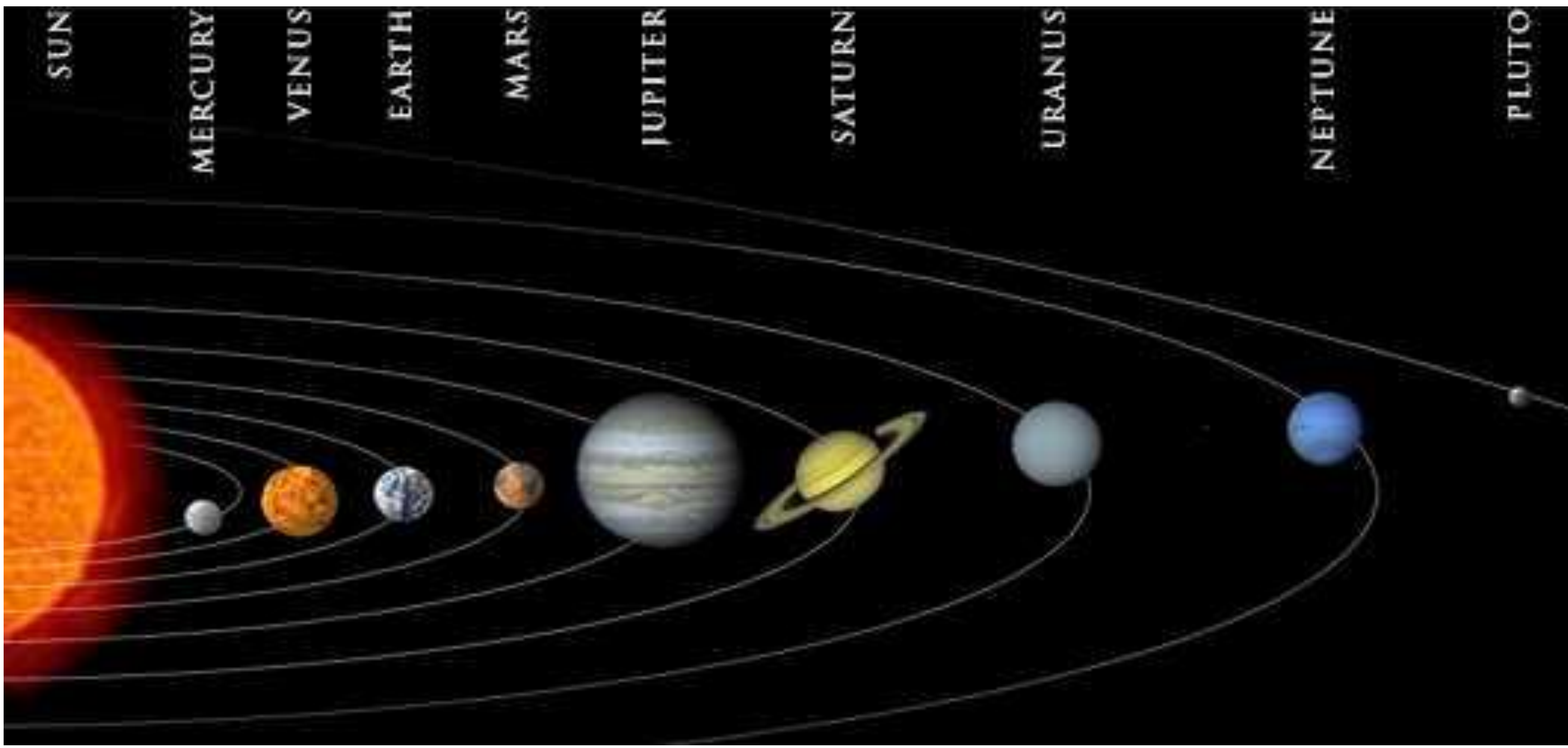
- A revolution occurs as the earth moves around the sun.
- Time for one revolution = 365 1/4 days = 8,766 hours
- The speed of earth’s revolution is about 18 miles per second.

Earth's Revolution



Earth's Orbit

- The path an object takes as it revolves around another object.



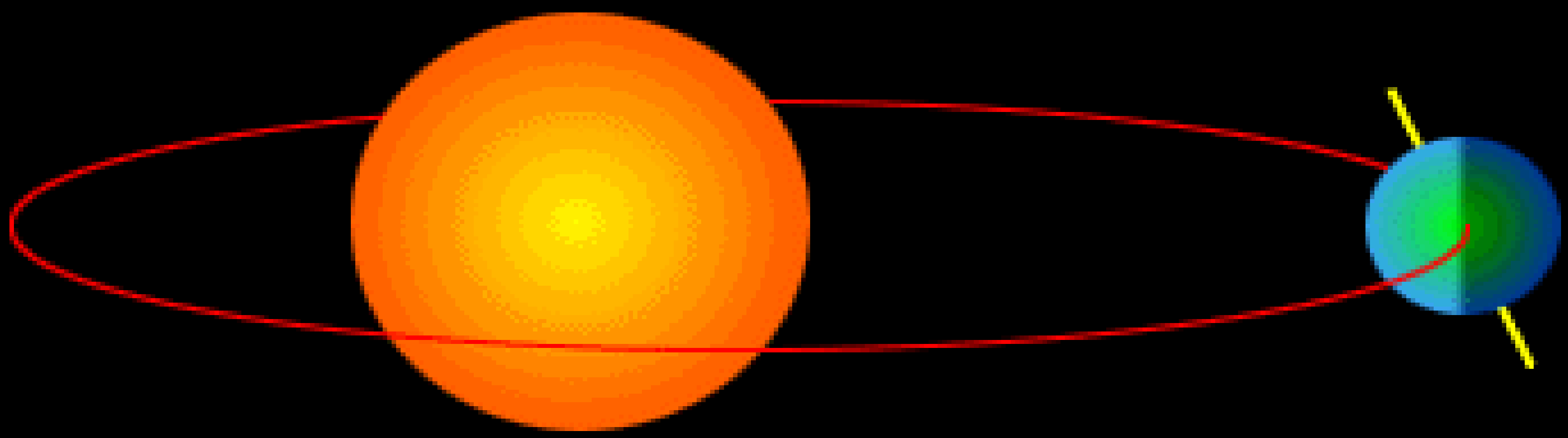
SEASONS

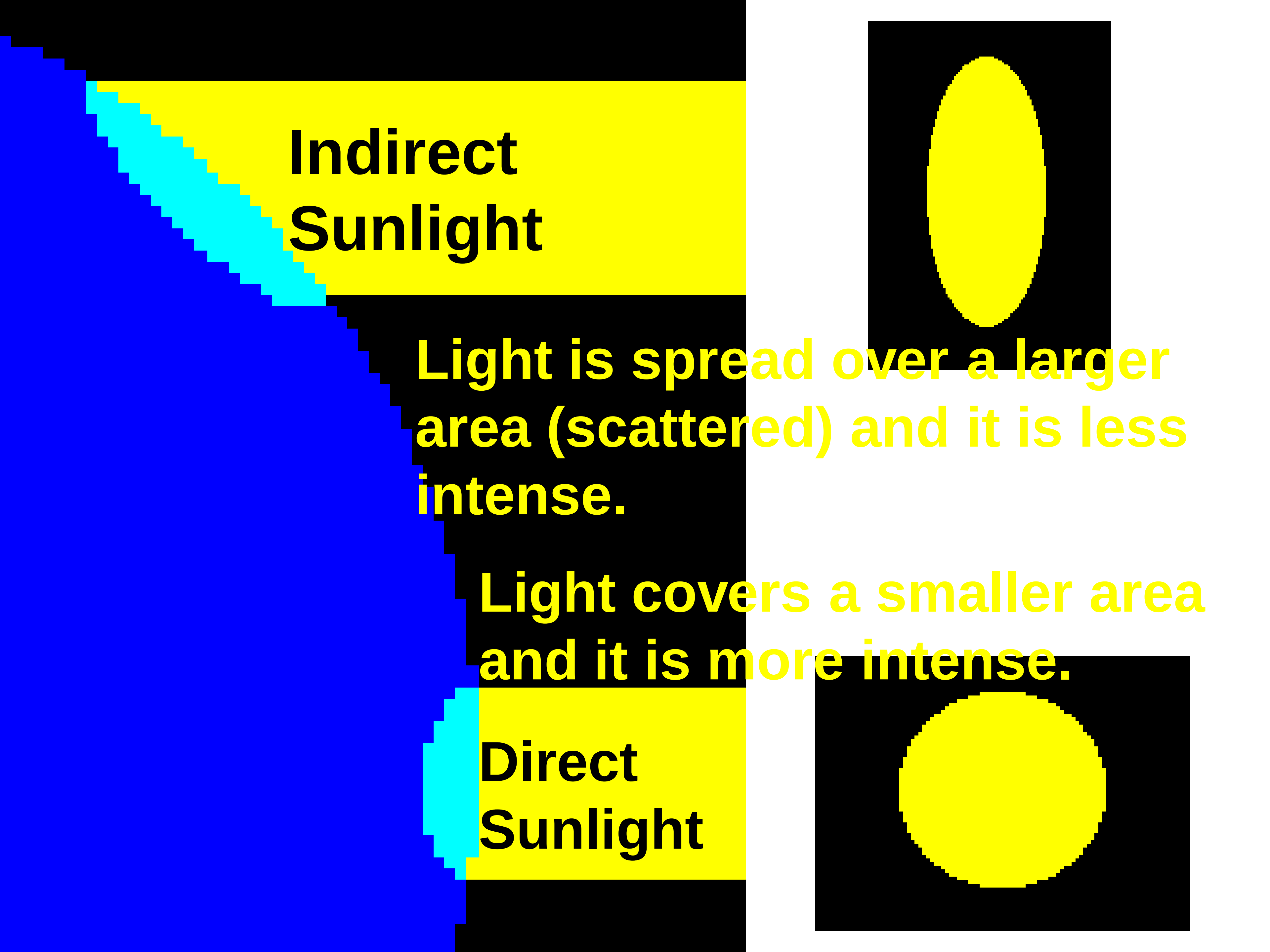
V. Cruz

The Earth's axis is tilted 23.5° from vertical.

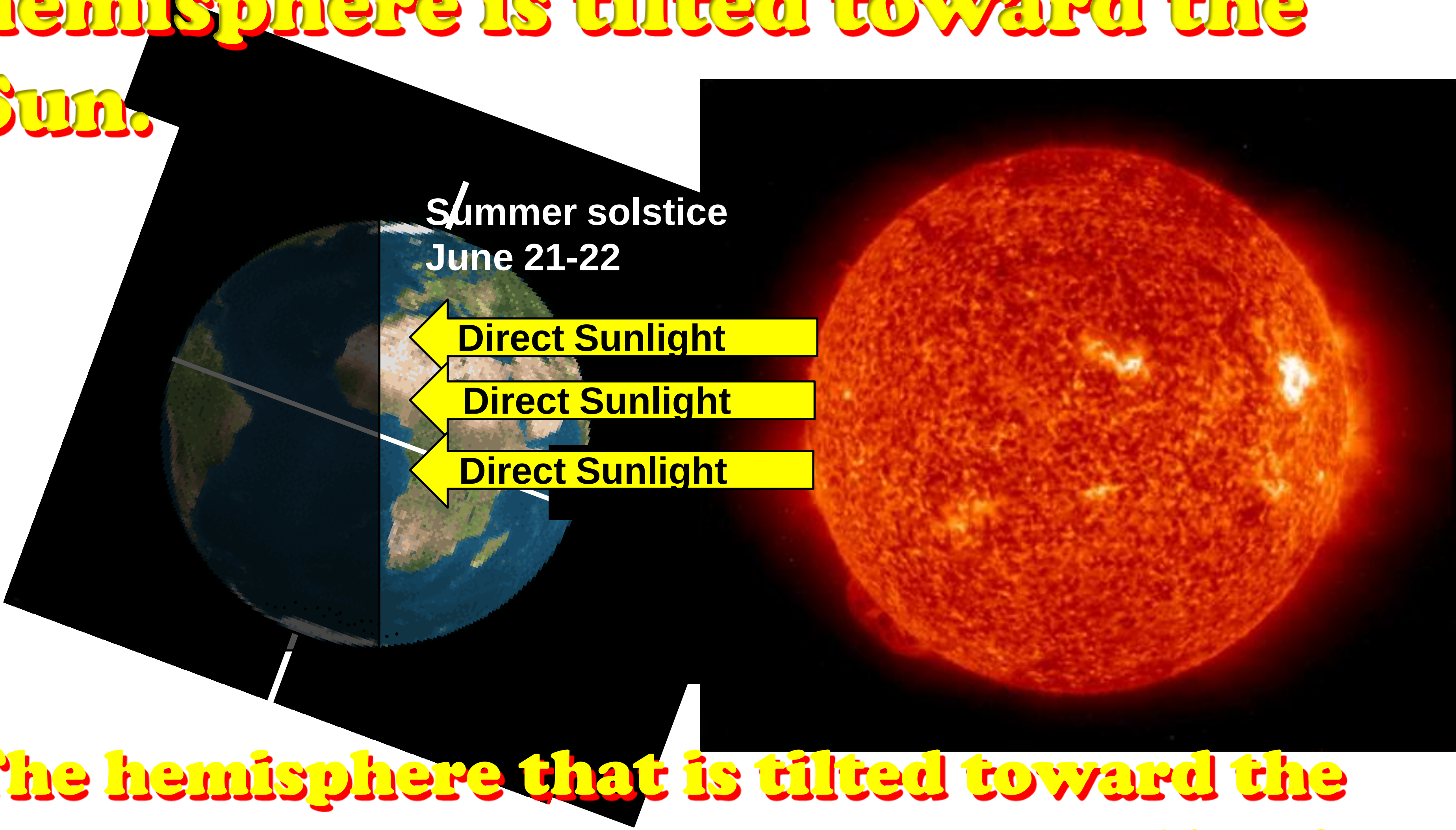
The axis always points in the same direction in space.

Seasons change depending on the amount of sunlight reaching the Earth as it revolves around the Sun.



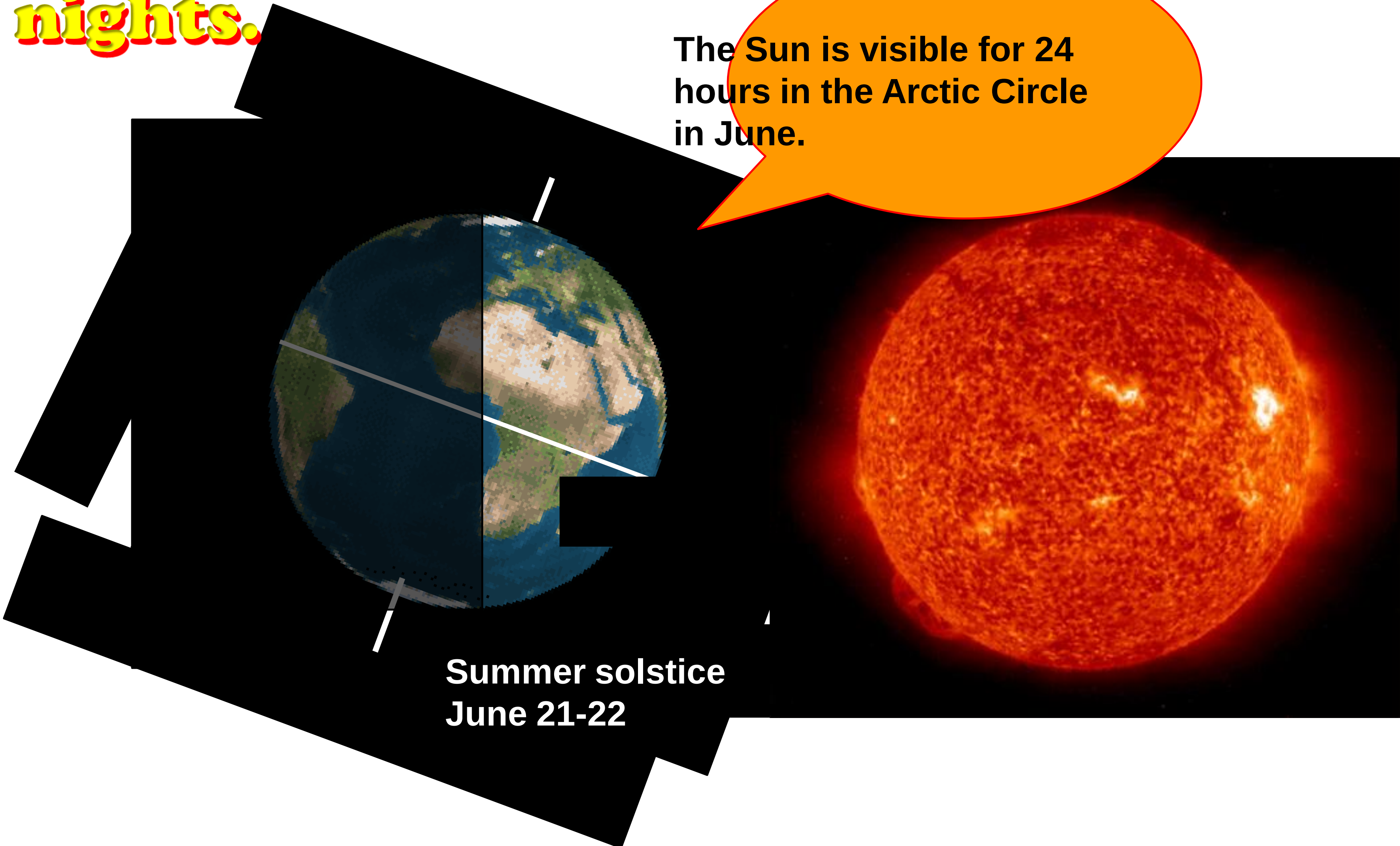

Indirect Sunlight
Light is spread over a larger area (scattered) and it is less intense.
Light covers a smaller area and it is more intense.
Direct Sunlight

During our summer the northern hemisphere is tilted toward the Sun.

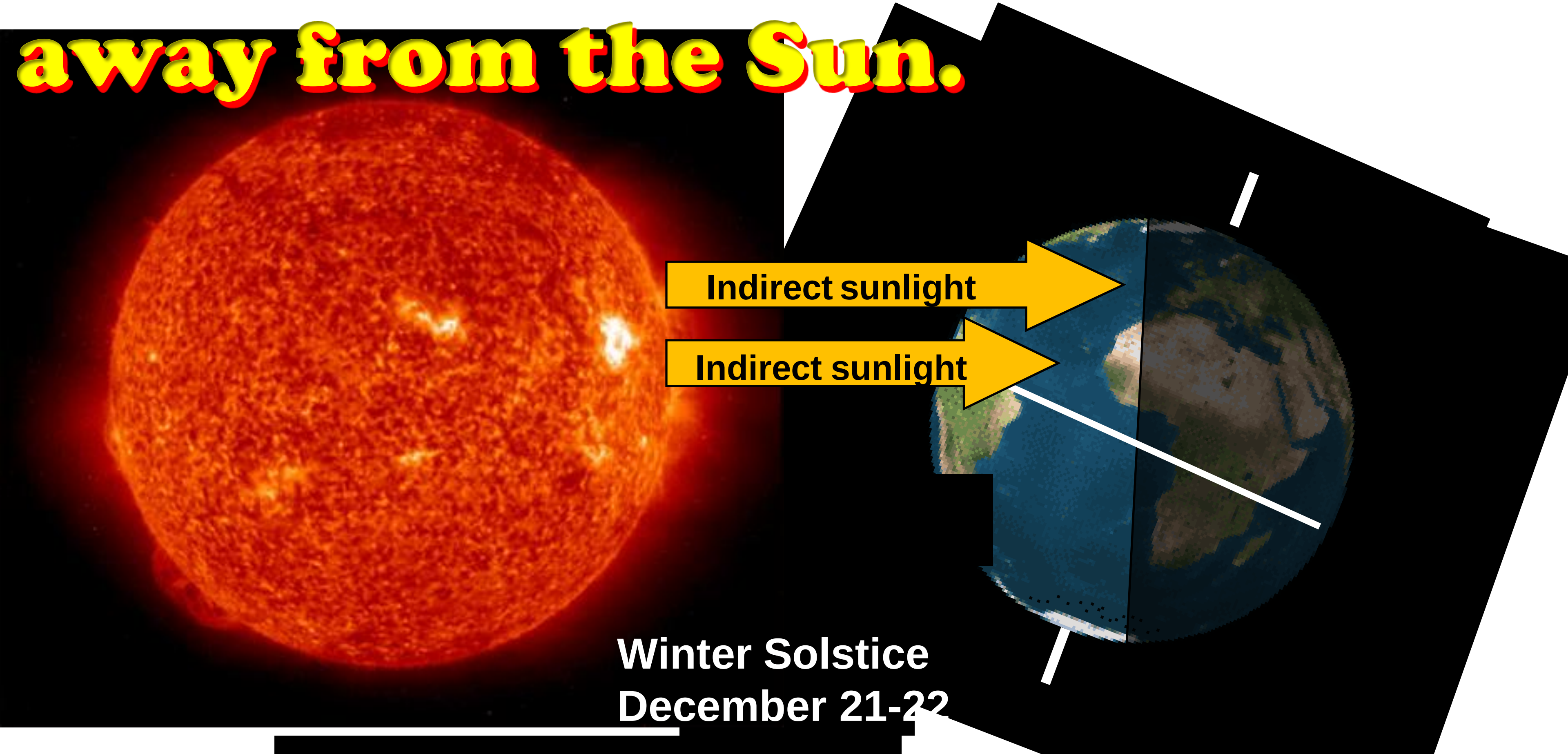


The hemisphere that is tilted toward the Sun receives more direct sunlight. The Sun rays are less scattered.

The hemisphere that is tilted toward the Sun has longer days and shorter nights.

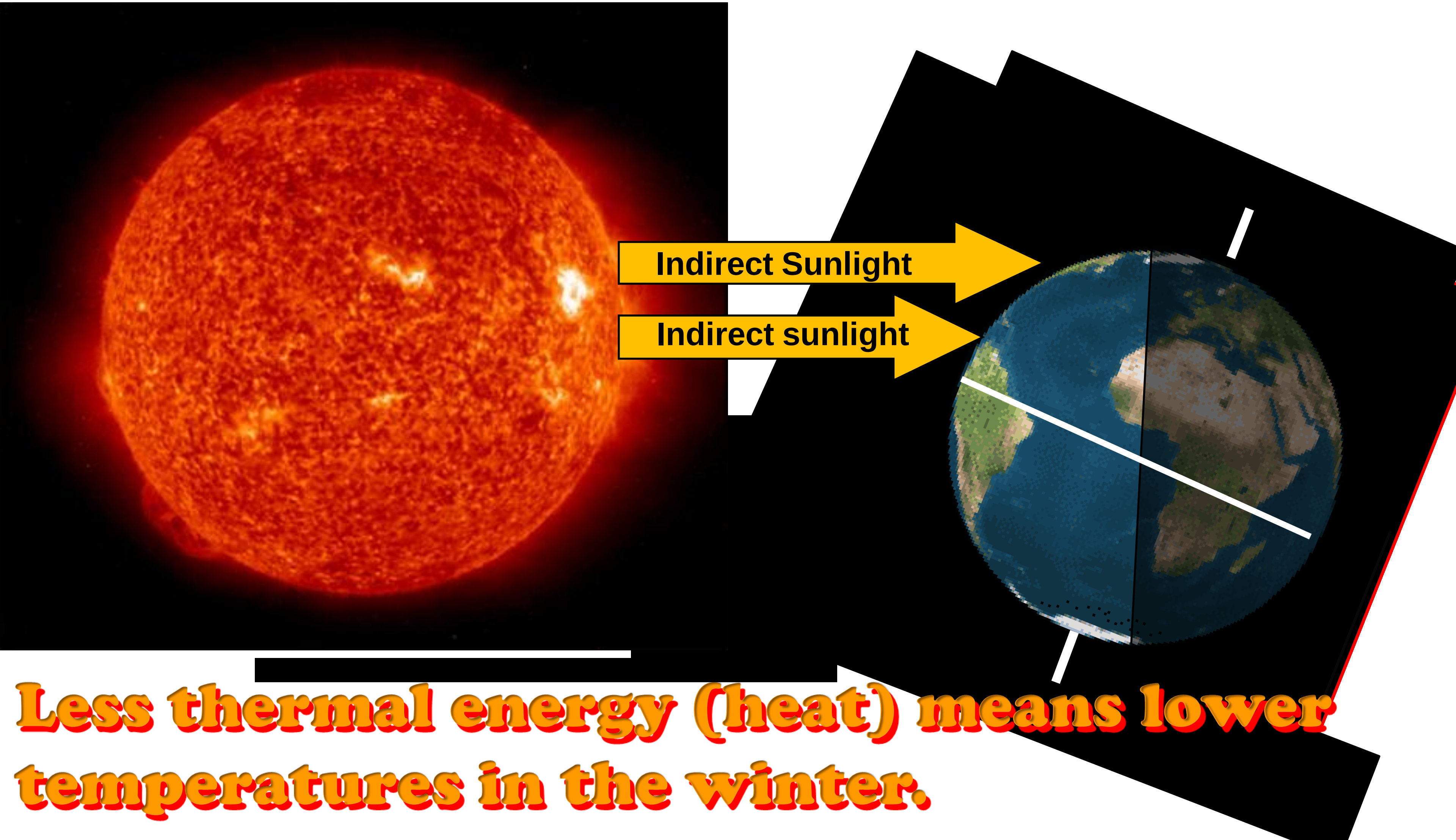


During our winter the northern hemisphere is tilted away from the Sun.



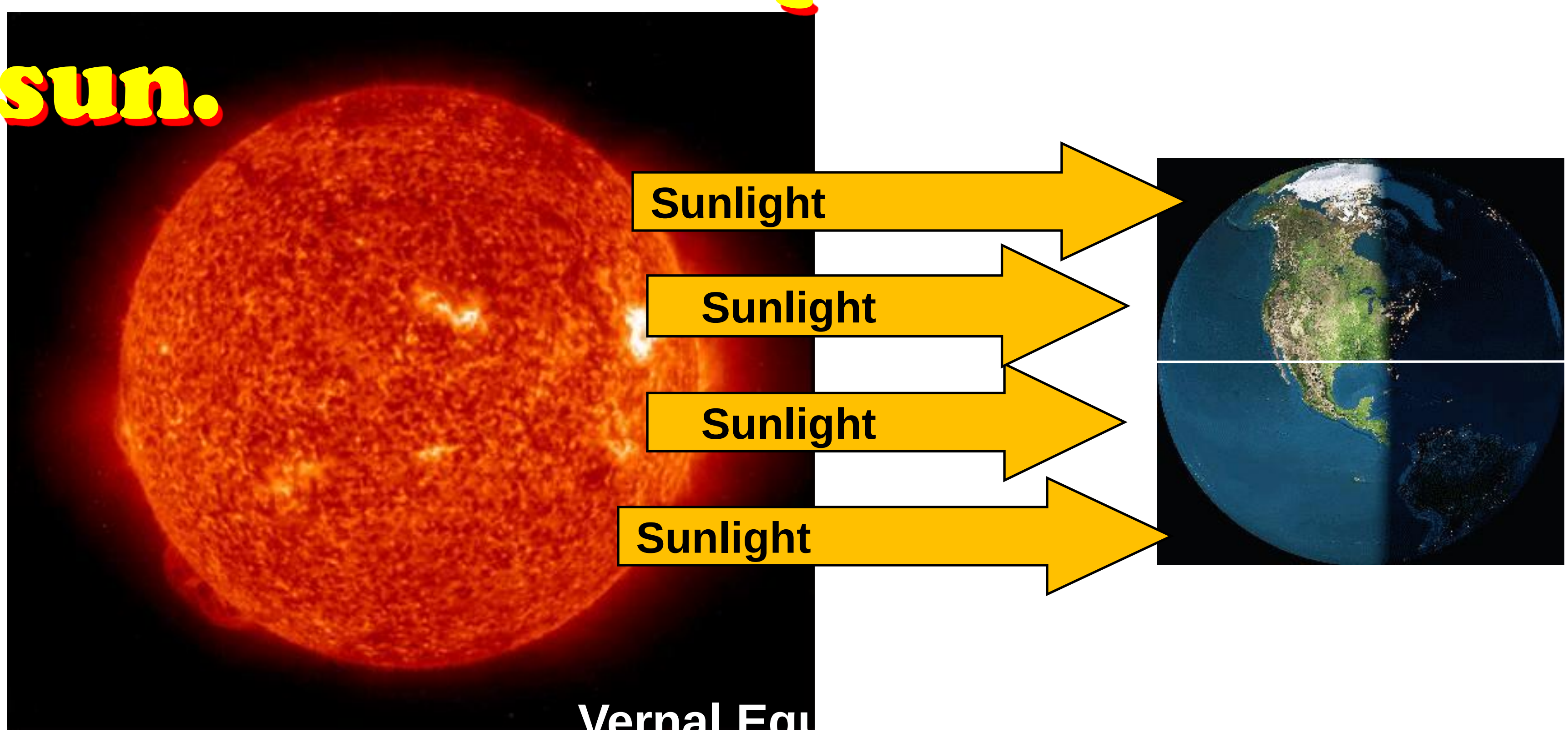
We are receiving sunlight at an indirect angle. The sun rays are scattered.

We receive less sunlight and less energy during winter.

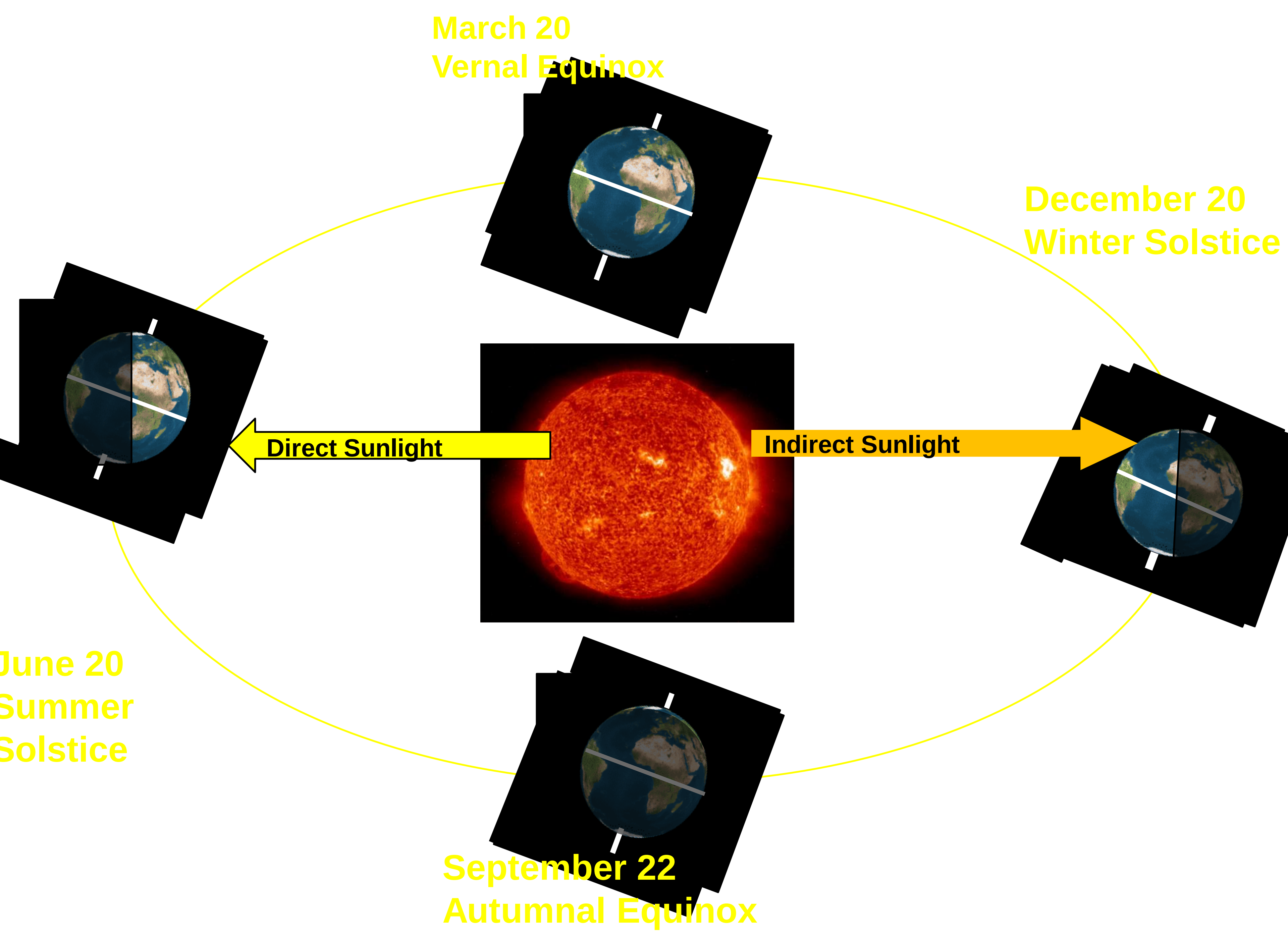


Less thermal energy (heat) means lower temperatures in the winter.

During fall and spring the Earth's axis is parallel to the sun.



The northern and southern hemispheres get equal amount of sunlight.


March 20
Vernal Equinox
December 20
Winter Solstice
Direct Sunlight
Indirect Sunlight
June 20
Summer
Solstice
September 22
Autumnal Equinox

Air Masses and Fronts

Air Mass

- **Large unit of air in which temperature and moisture conditions are uniform at a given altitude.**

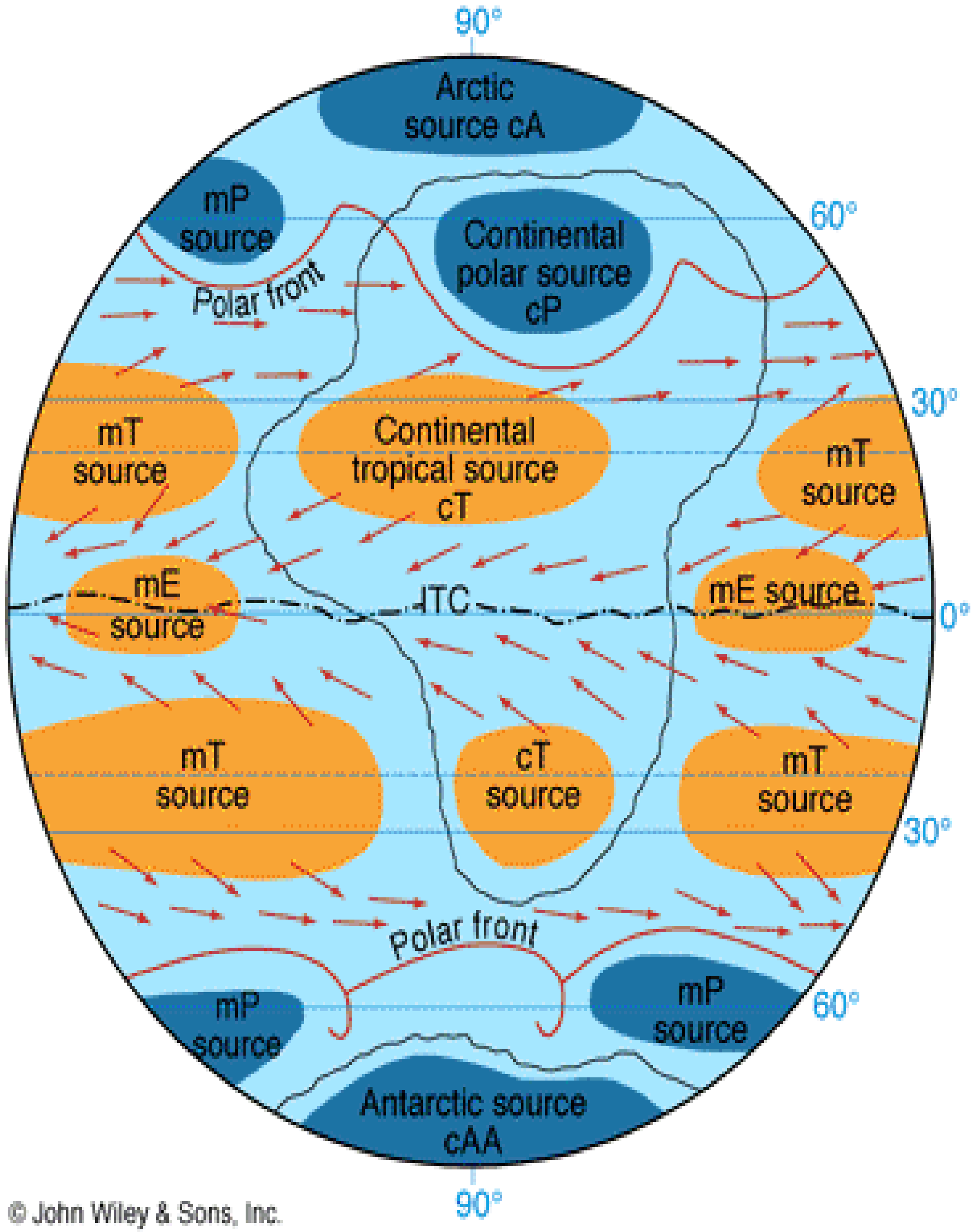
- **Moves separately from surroundings**

- **temperature and moisture conditions determined by SOURCE REGION of air mass**

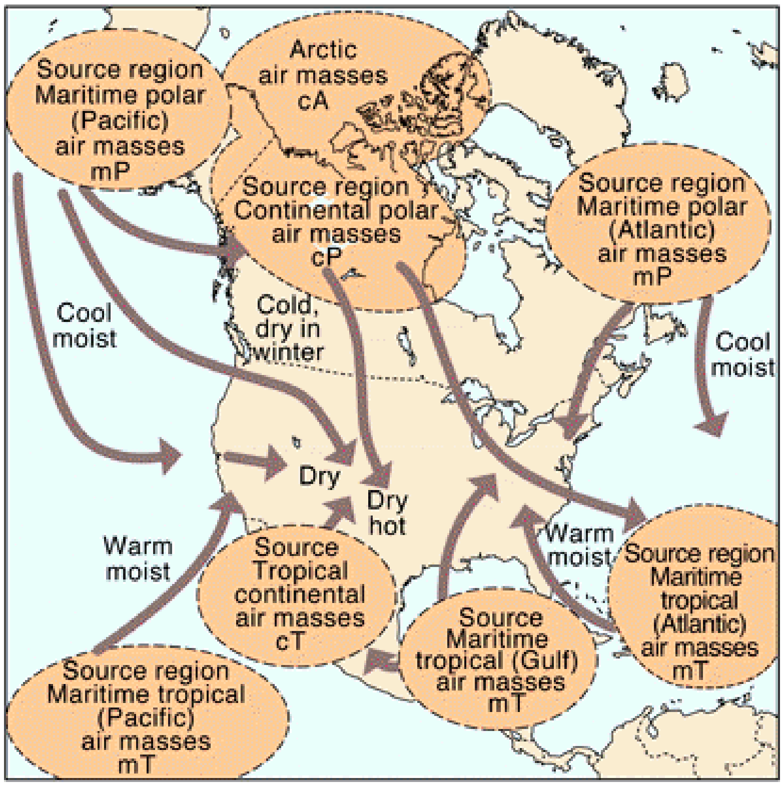
Properties of source region:

- **Moisture:**
  - **continental “c”, maritime “m”**
  - **determined by underlying surface (ocean or land)**
- **Thermal:**
  - **Polar “P”, Tropical “T”, Equatorial “E”, Arctic “A”**
  - **determined by latitude**

- **Combination:**
  - cP
  - mP
  - mT
  - cT
  - cA (or cAA)
  - mE



Air Masses that affect U.S. weather:



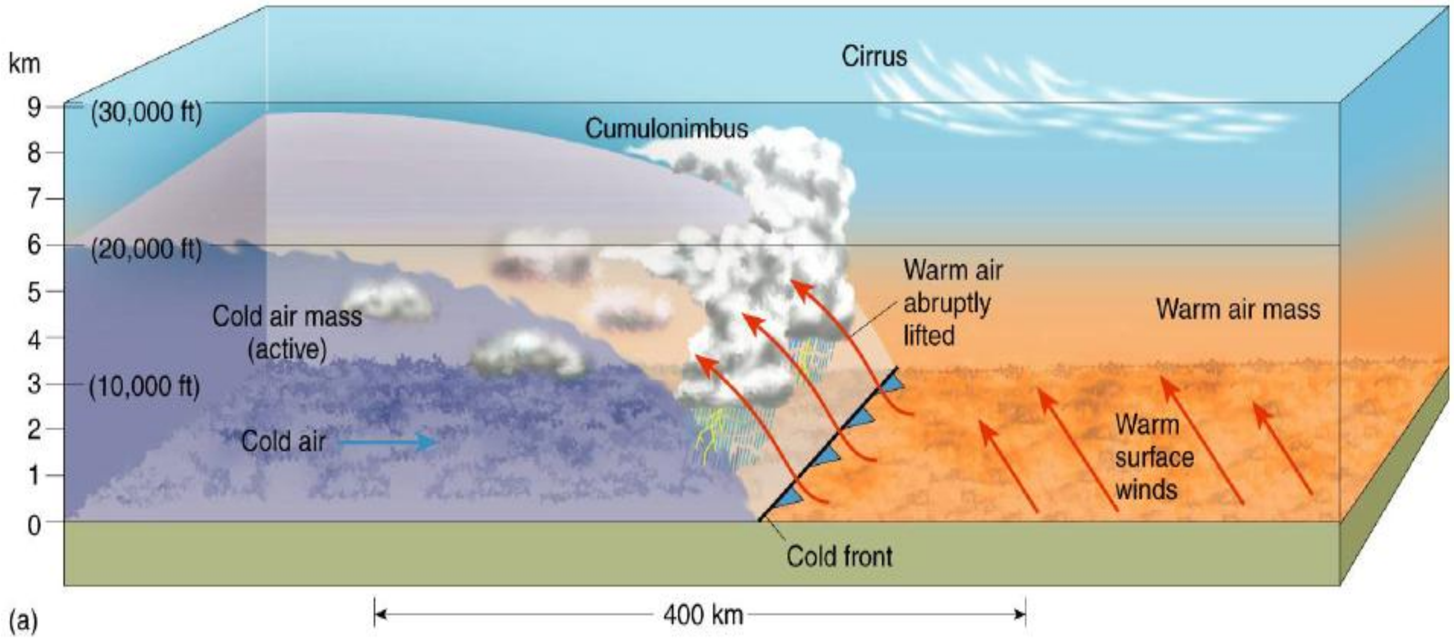
Data from U.S. Department of Commerce

- **cP:** cold dry air from Canada; High pressure
- **cA:** from Arctic Ocean region; extremely cold
- **mP**, **<u>Pacific</u>:** cool, moist air
  mP, <u>Atlantic</u>: cool, moist, but often no effect due to prevailing wind
- **mT**: **<u>from Gulf and Caribbean</u>:** hot, wet air
- **mT**, **<u>Pacific</u>:** slightly cooler and drier
- **cT**: **hot dry air; persistent**

Air masses

- modify the local weather of places they invade are modified by the places they invade

- **Front: the boundary between two unlike air masses**
  - **unlike in temperature, moisture, or both**
- **named according to motion of the cold air**



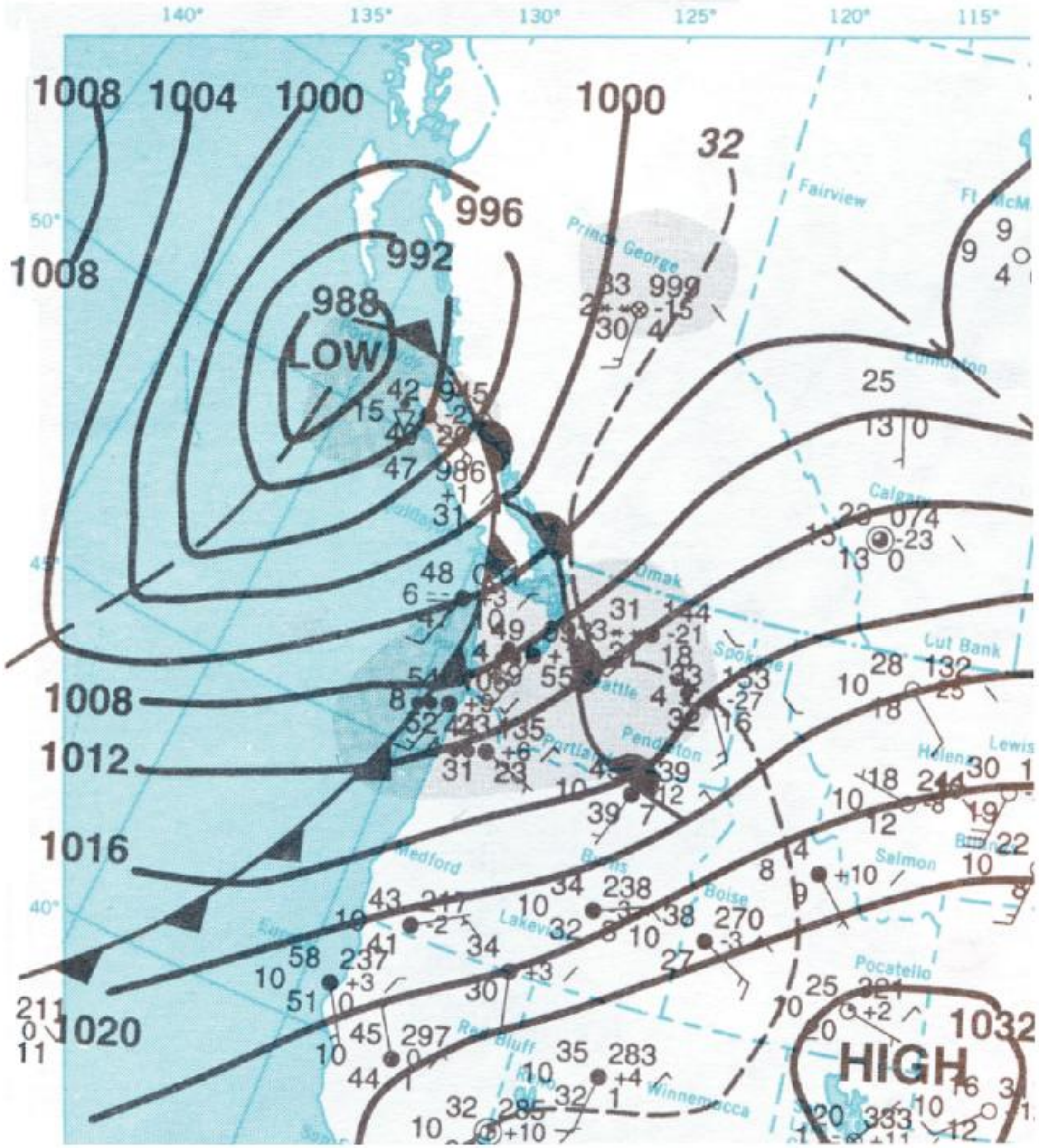
km
9
(30,000 ft)
8
7
6
(20,000 ft)
5
4
3
(10,000 ft)
2
1
0
Cirrus
Cumulonimbus
Warm air
abruptly
lifted
Warm air mass
Cold air mass
(active)
Cold air
Warm
surface
winds
Cold front
400 km

(a)

Cold front

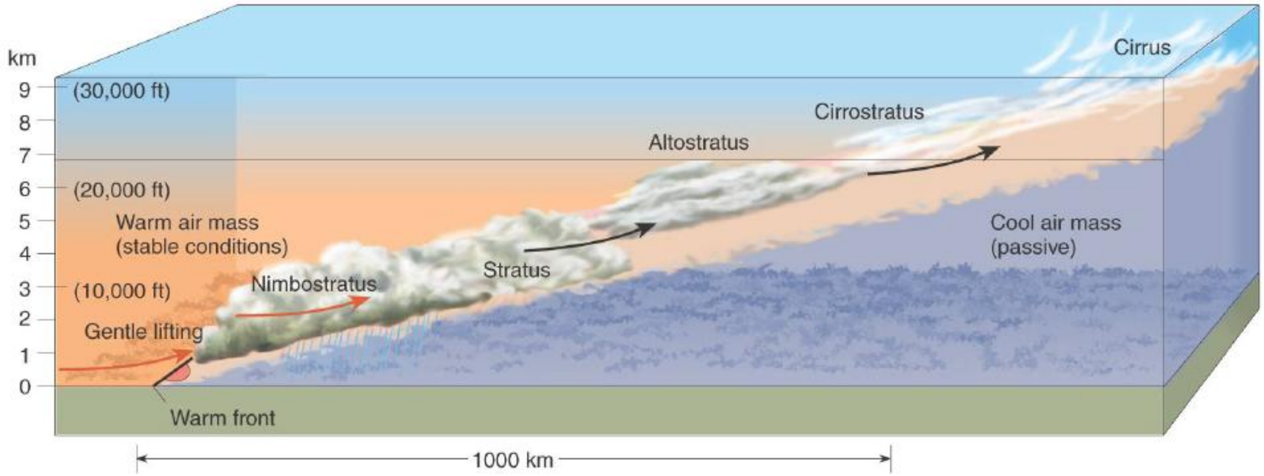
- **Cold air is advancing**
- **20 mph**
- **leading edge is steep (1:40)**
- **unstable along front: warm air rises over cold air rapidly**
- **short duration (hours)**
- **heavy precipitation in narrow band behind front**
- **followed by clear weather**
- **Symbol :**

(b)



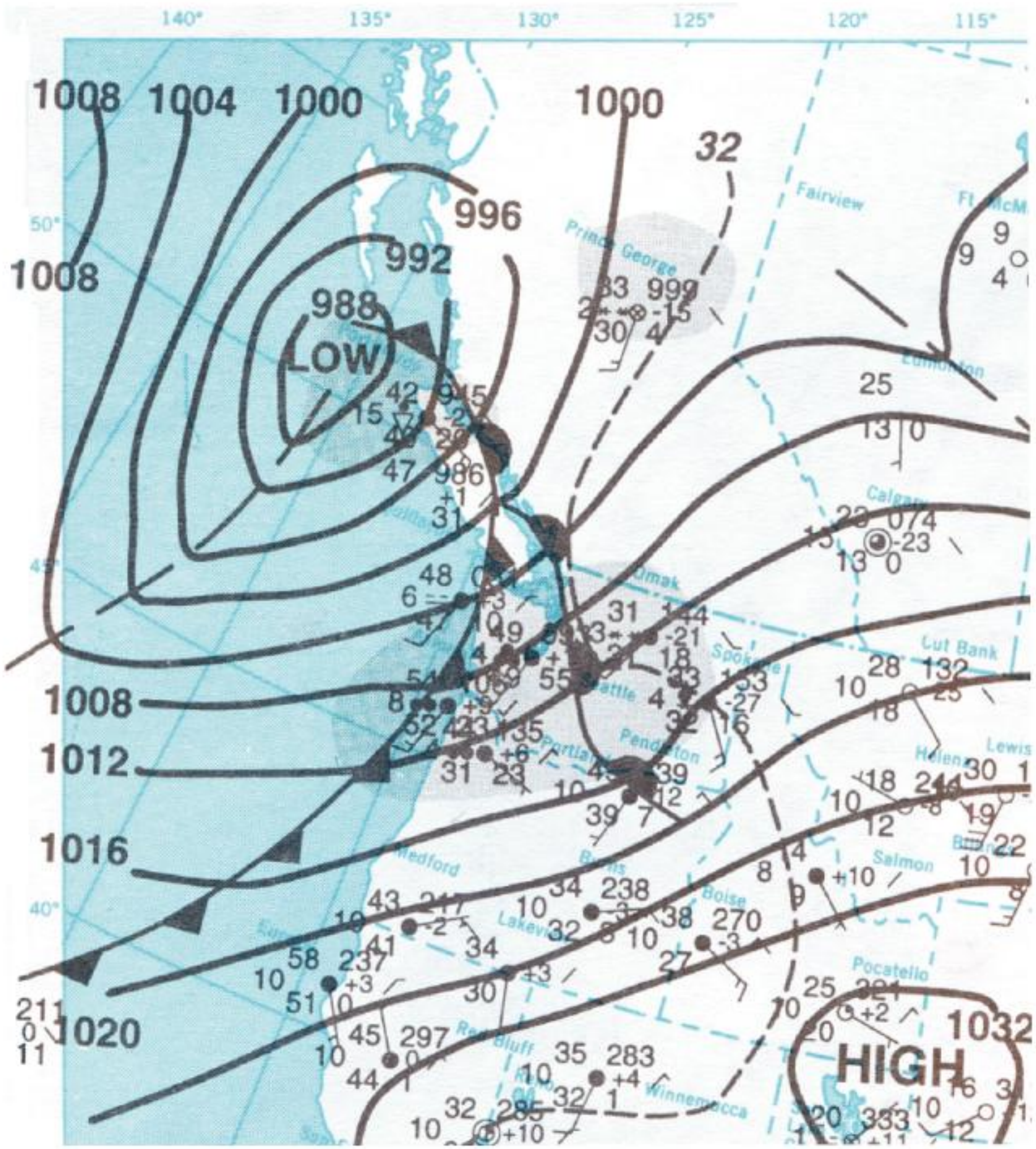
140°
135°
130°
125°
120°
115°
50°
45°
40°
1008
1004
1000
996
992
988
LOW
1000
32
1008
1008
1012
1016
1020
1032
HIGH
Prince George
Fairview
Edmonton
Calgary
Umak
Spokane
Seattle
Portland
Pendleton
Cut Bank
Helena
Lewis
Salmon
Medford
Burns
Boise
Lakeview
Pocatello
Red Bluff
Reno
Winnemucca

Warm Front


km
9
8
7
6
5
4
3
2
1
0
(30,000 ft)
(20,000 ft)
(10,000 ft)
Cirrus
Cirrostratus
Altostratus
Warm air mass
(stable conditions)
Cool air mass
(passive)
Stratus
Nimbostratus
Gentle lifting
Warm front
1000 km

Warm front

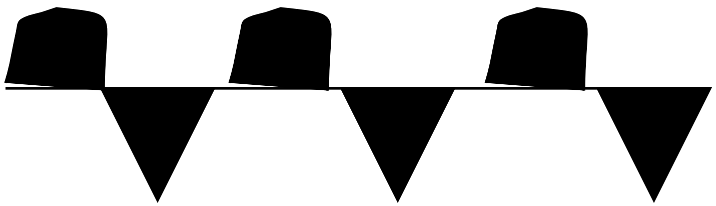
- **Cold air is retreating**
- **10 mph**
- **leading edge is not steep (1:150)**
- **warm air gently climbs over cold air (not as unstable as cold front)**
- **duration (days)**
- **stratus and nimbostratus clouds**
- **light precipitation in wide band ahead of front**
- **Symbol:**



140°
135°
130°
125°
120°
115°
50°
45°
40°
1008
1004
1000
996
992
988
LOW
1000
32
1008
1008
1012
1016
1020
1032
HIGH
Fairview
Prince George
Edmonton
Calgary
Omak
Spokane
Seattle
Portland
Pendleton
Cut Bank
Helena
Lewistown
Salmon
Medford
Burns
Boise
Lakeview
Pocatello
Red Bluff
Reno
Winnemucca

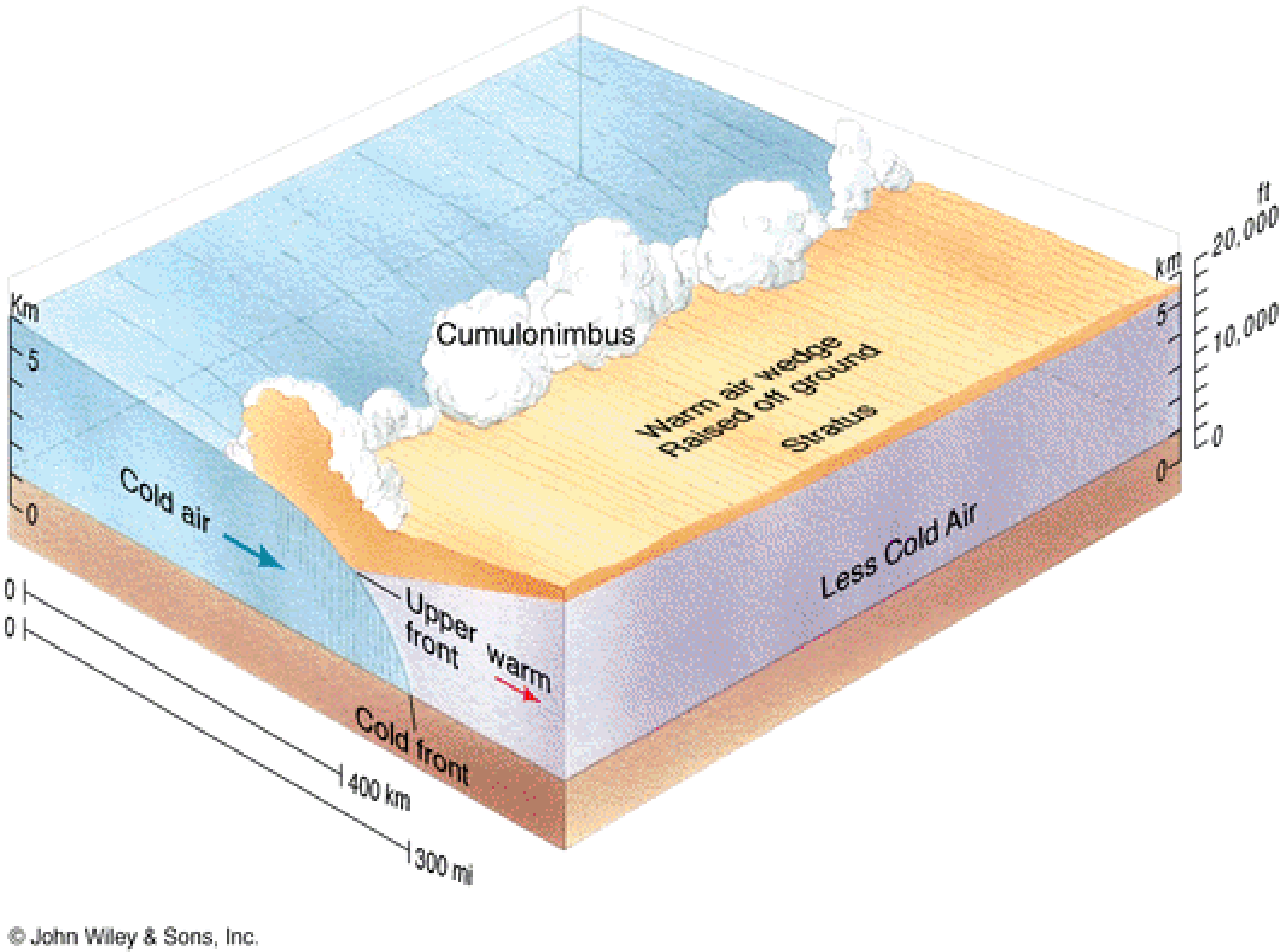
Stationary front

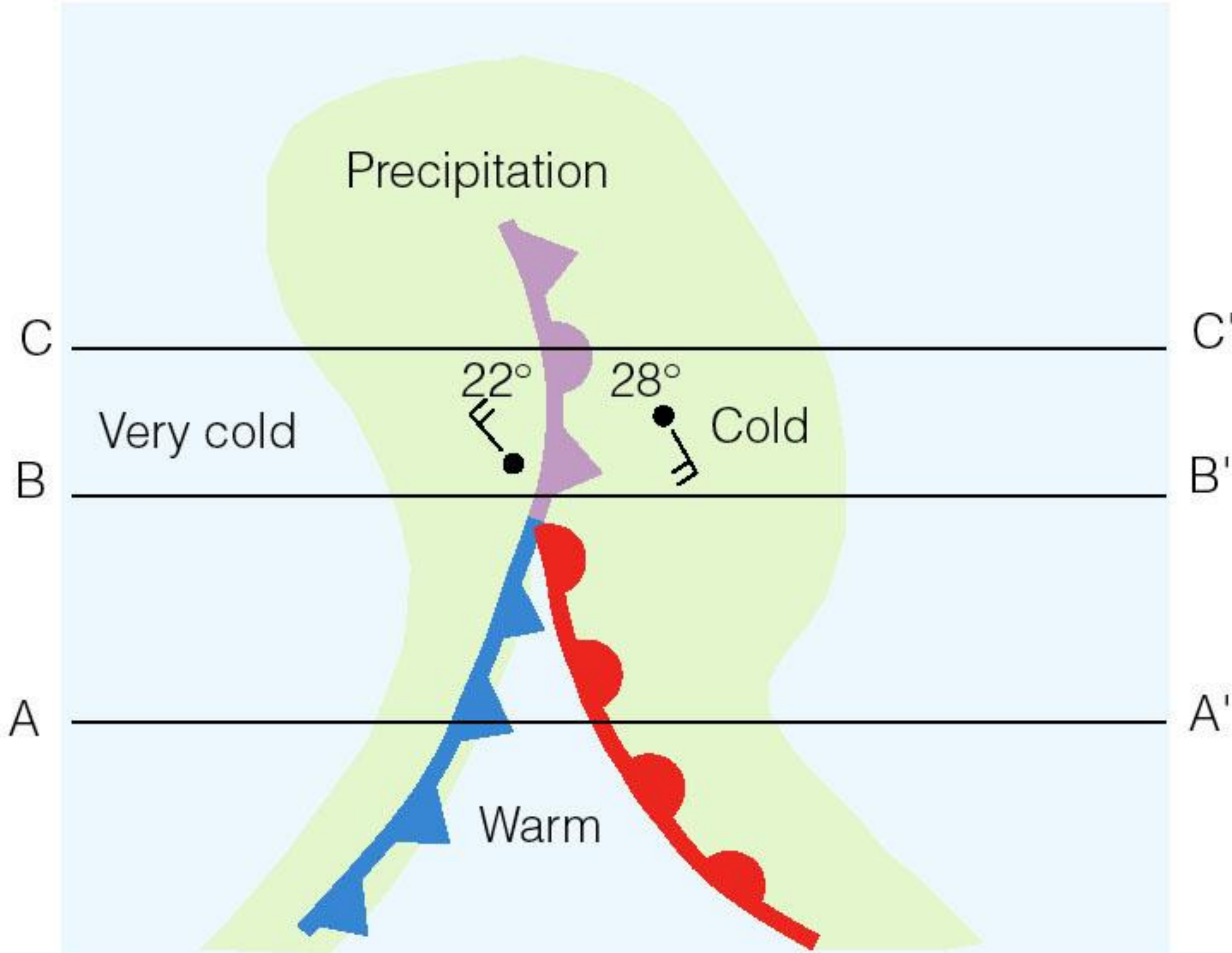
- no movement of air masses
- precipitation at the front:
  - not much on warm side
  - stratus clouds and steady precipitation on cold side
- Weather map symbol :



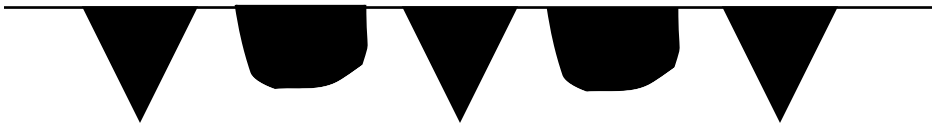
Occluded front

Occluded front occurs when a cold front overtakes a warm front

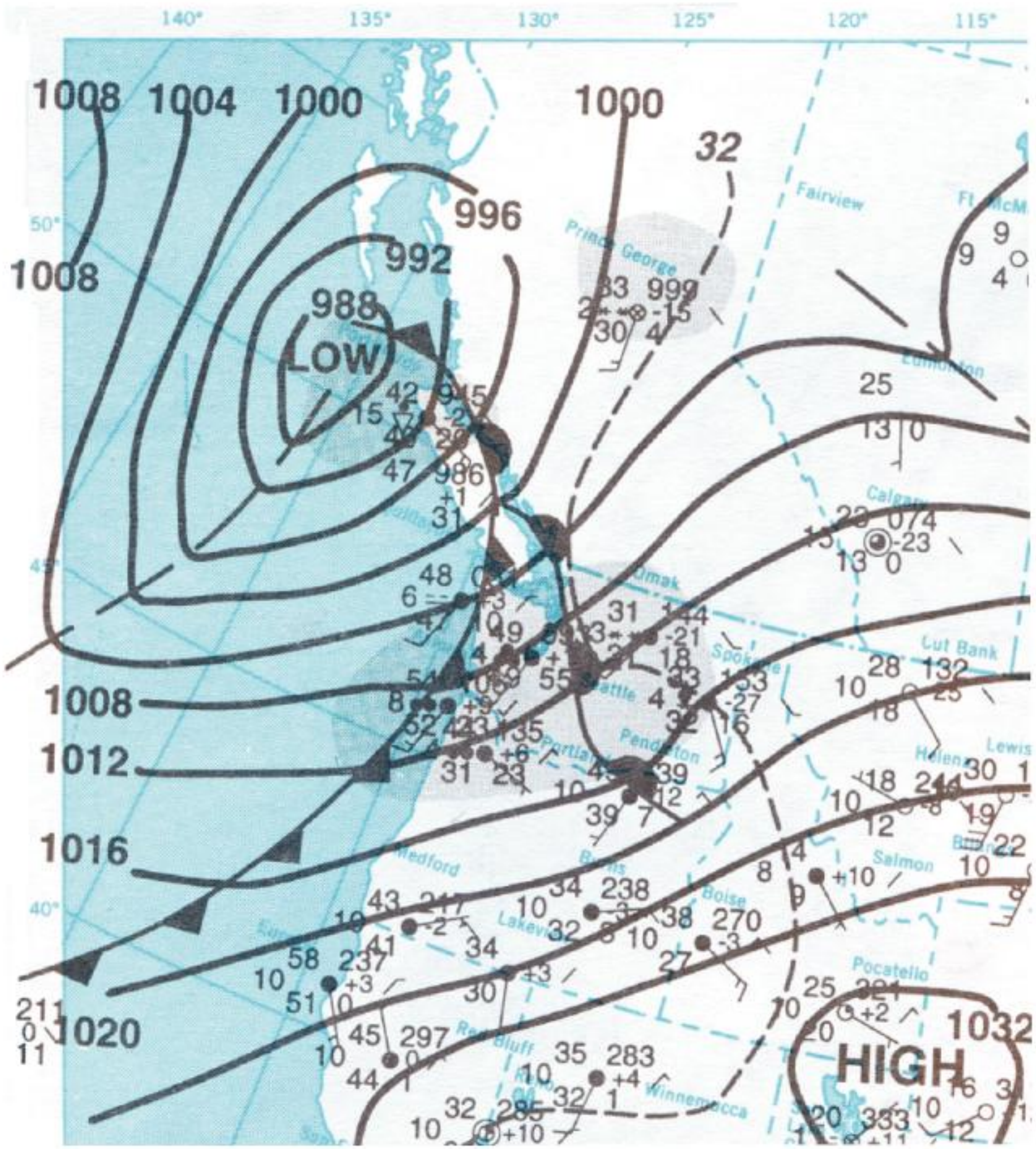



Precipitation
C
C'
22°
28°
Very cold
Cold
B
B'
A
A'
Warm

- In occluded fronts, warm air wedge is lifted off of ground; clouds are high, then they lower and thicken into middle and low clouds; precipitation occurs

- Symbol : 

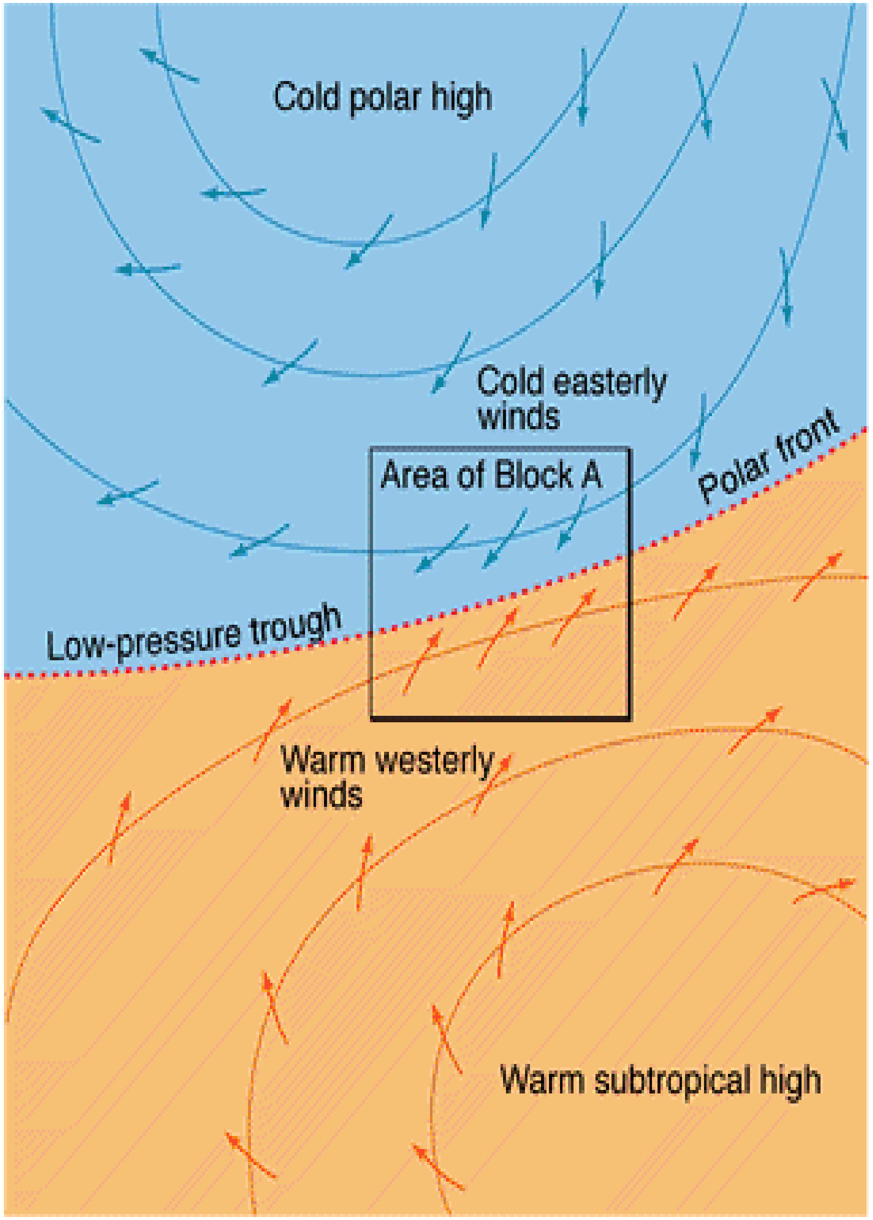
- Occluded fronts are associated with storms called “wave cyclones”



140°
135°
130°
125°
120°
115°
50°
45°
40°
1008
1004
1000
996
992
988
LOW
1000
32
1008
1012
1016
1020
1032
HIGH
Prince George
Fairview
Calgary
Omak
Cut Bank
Pendleton
Helena
Salmon
Medford
Boise
Pocatello
Winnemucca

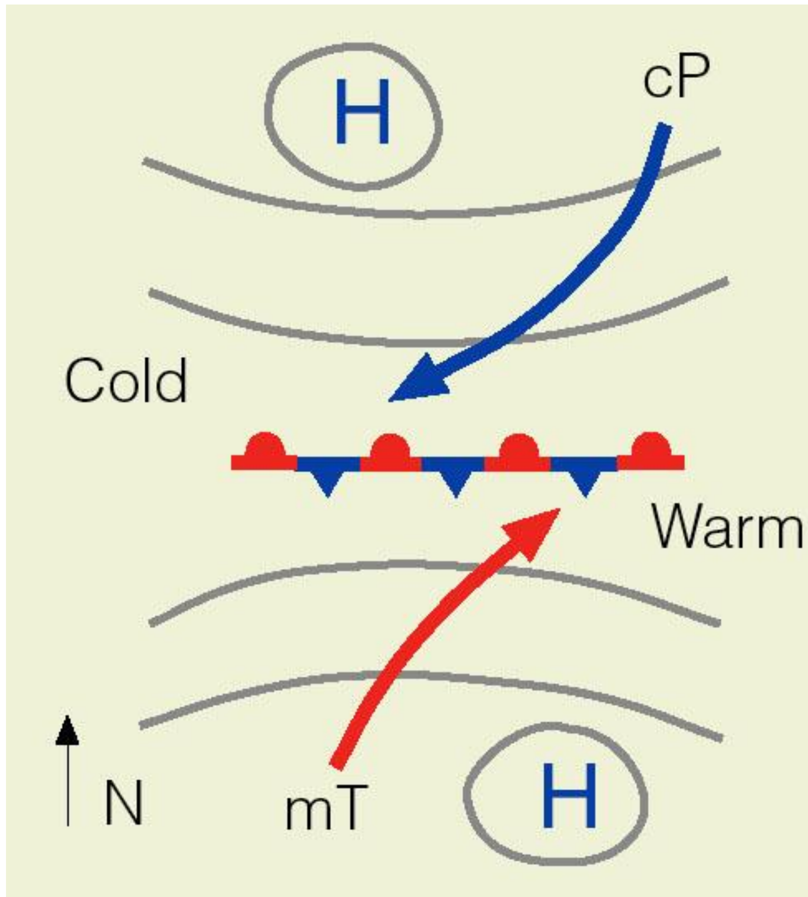
Cyclogenesis: the development of a wave cyclone

- Wave cyclone:
  - migrating center of low pressure
  - causes storms in the midlatitudes
  - Form along polar front



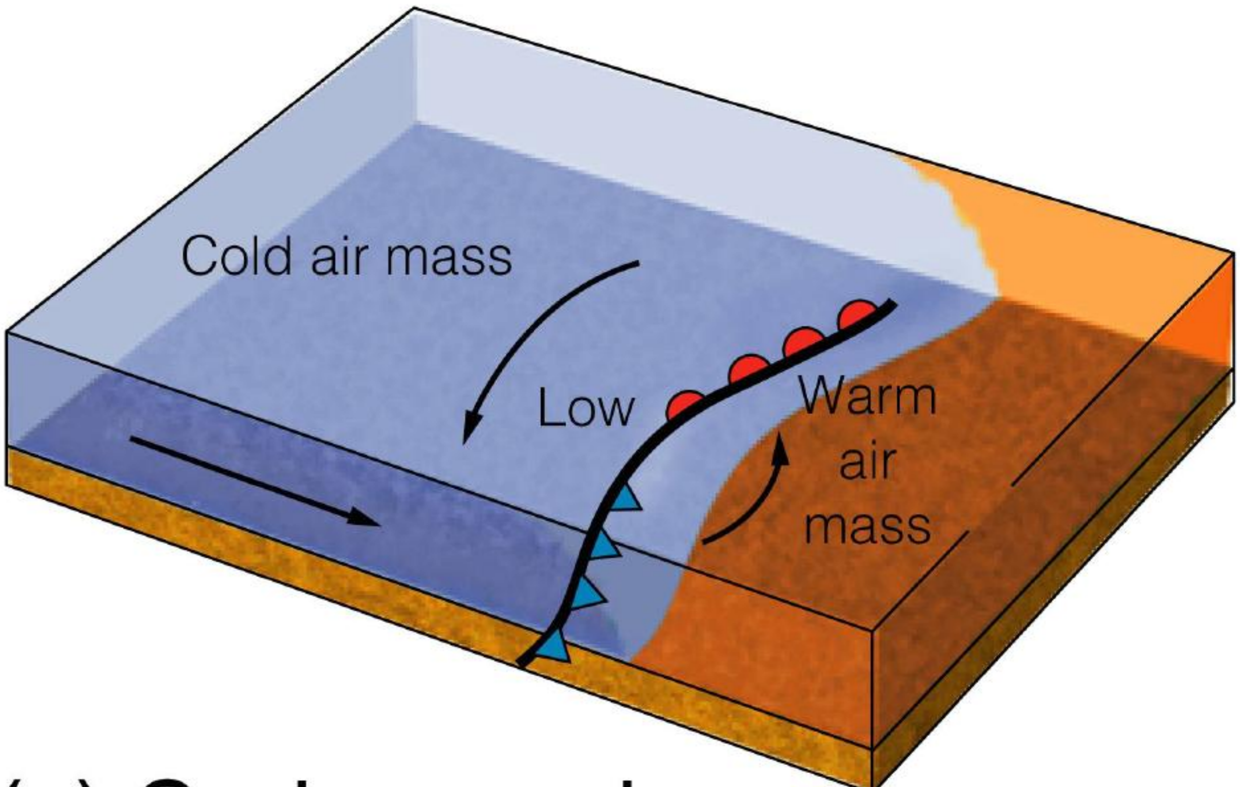
Favorable conditions:

- **“Trough” of low pressure between two Highs along polar front**
- **converging air**
- **unstable**

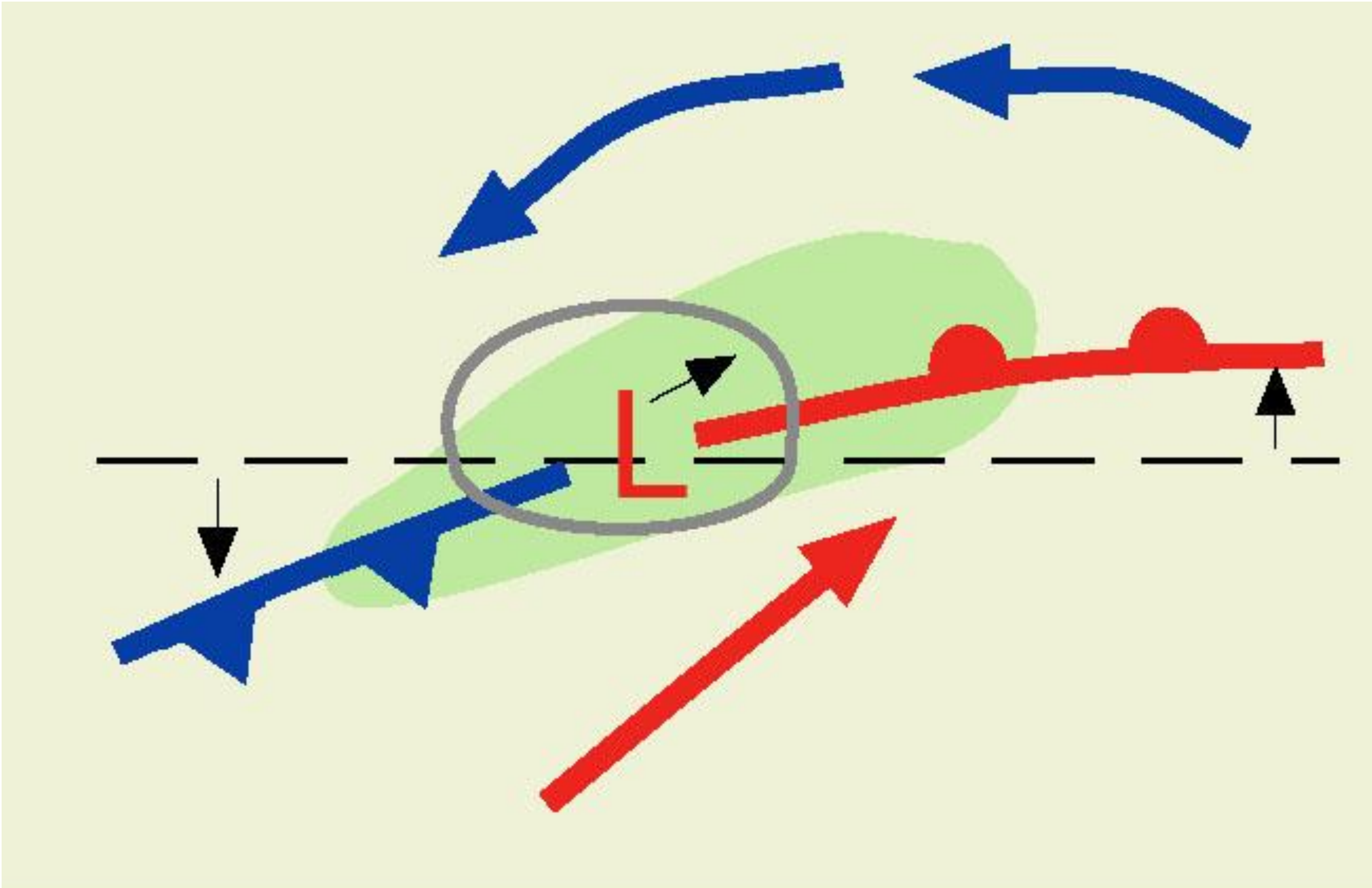

H
cP
Cold
Warm
N
mT
H

1. Early stage

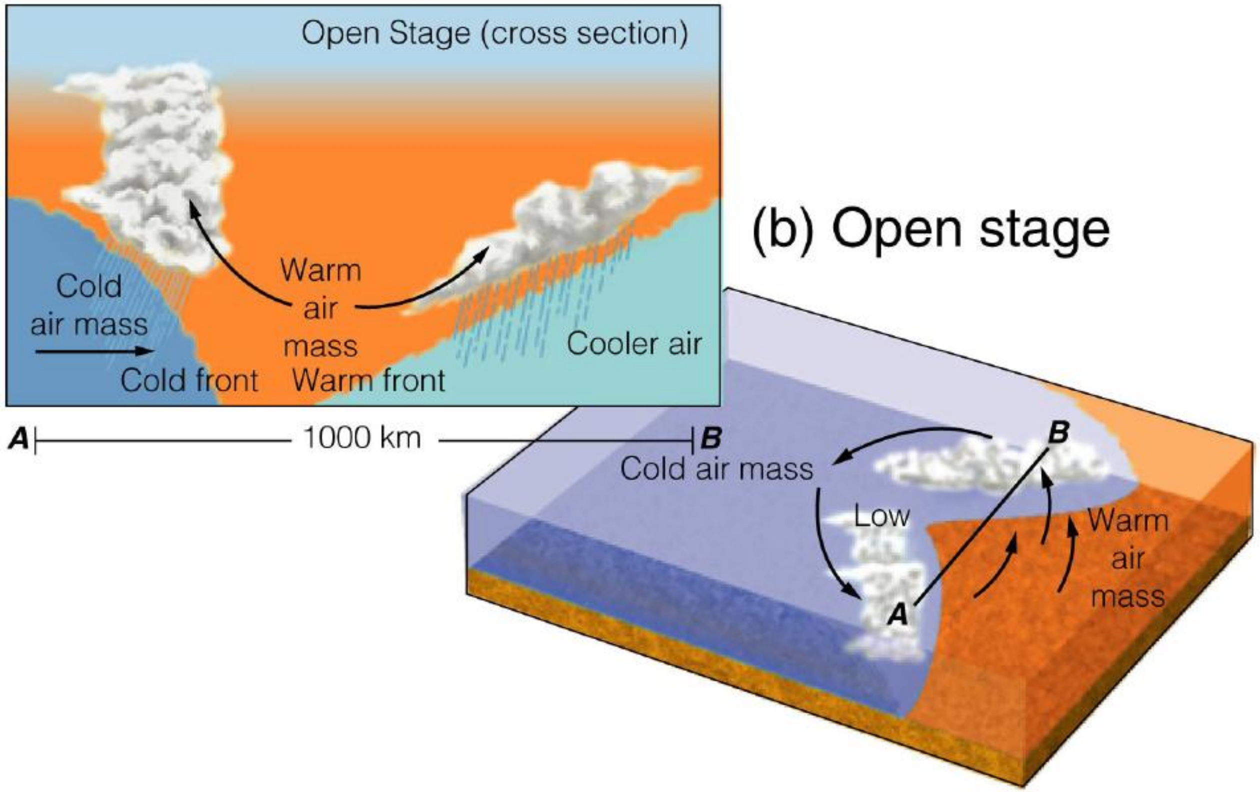
surface convergence; lifting around Low



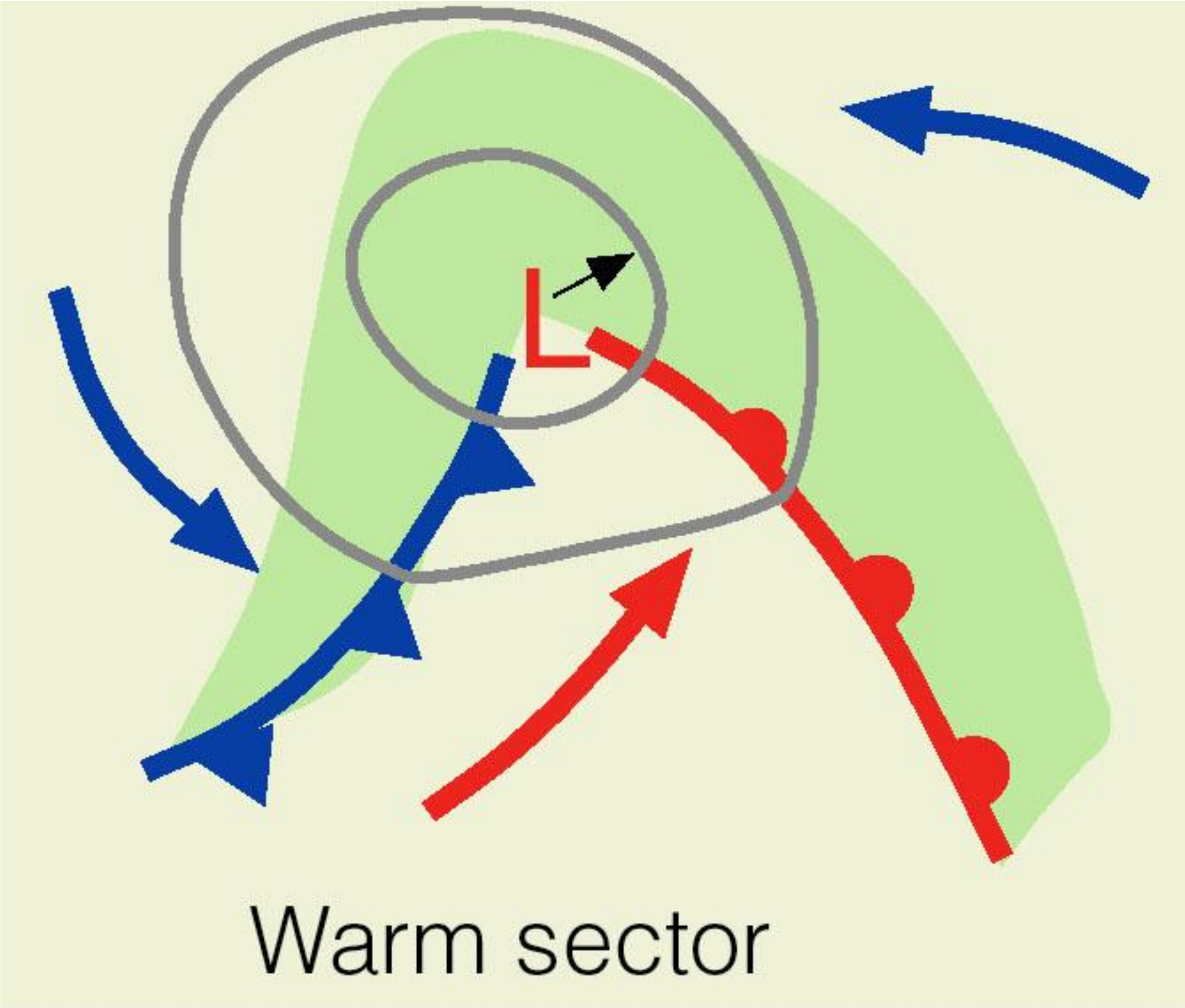
(a) Cyclogenesis

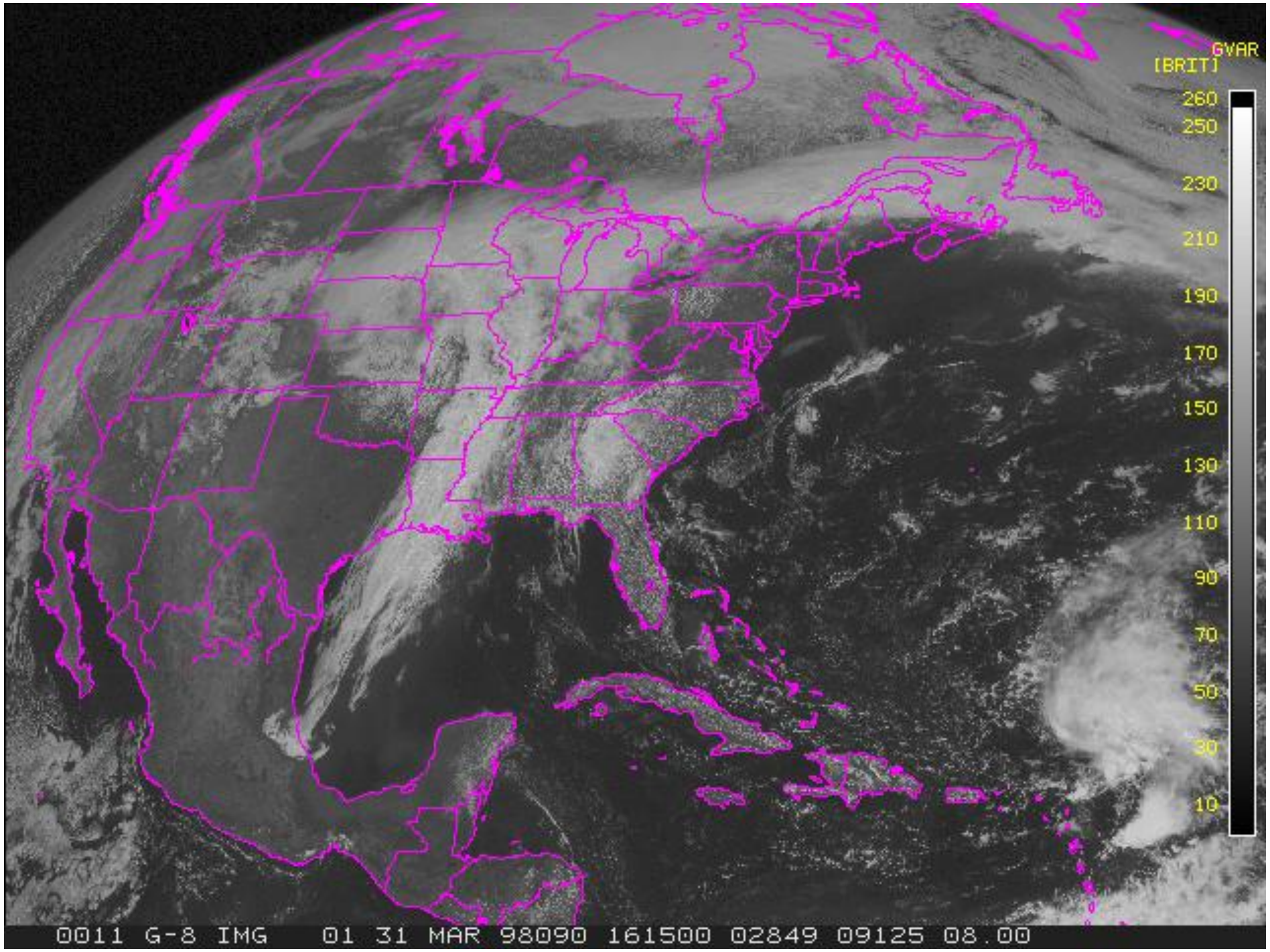


2. Open Stage

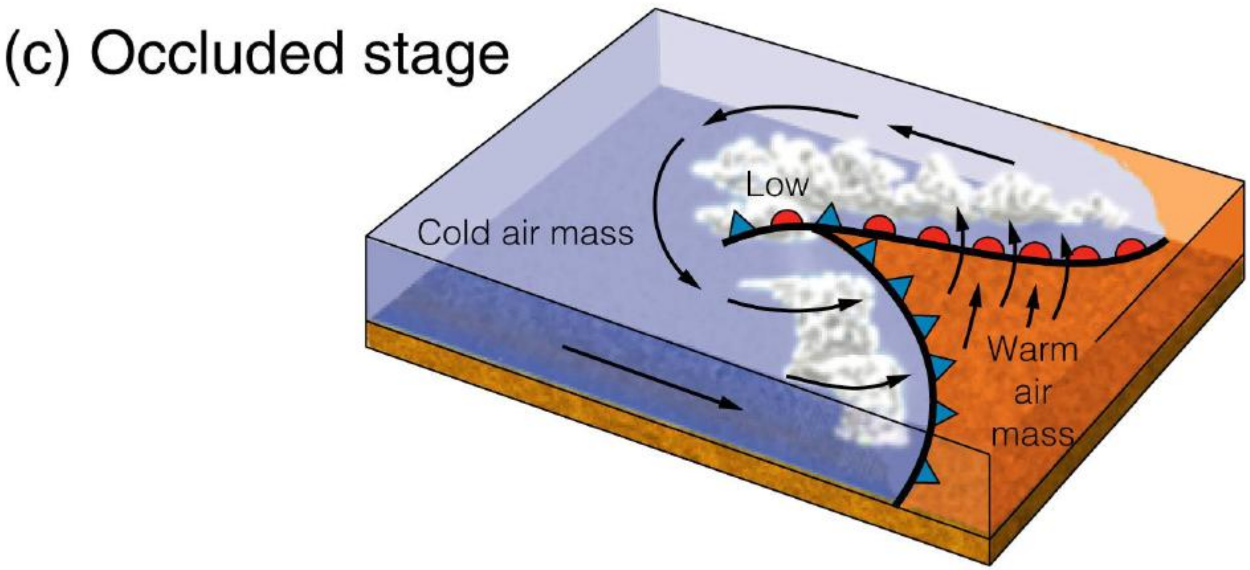


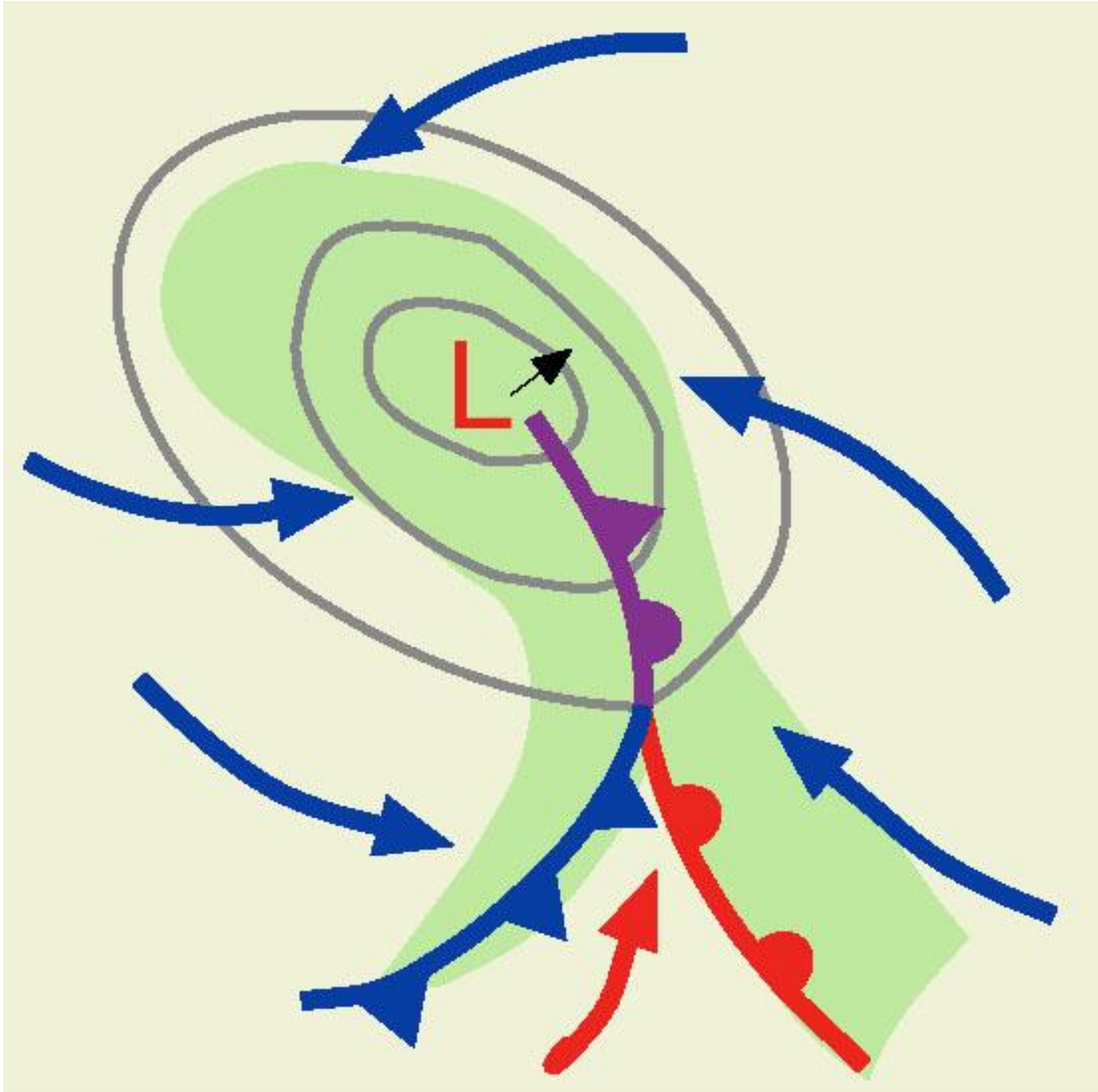
Open Stage (cross section)
Cold
air mass
Warm
air
mass
Cooler air
Cold front
Warm front
A
1000 km
B
(b) Open stage
B
Cold air mass
Low
Warm
air
mass
A

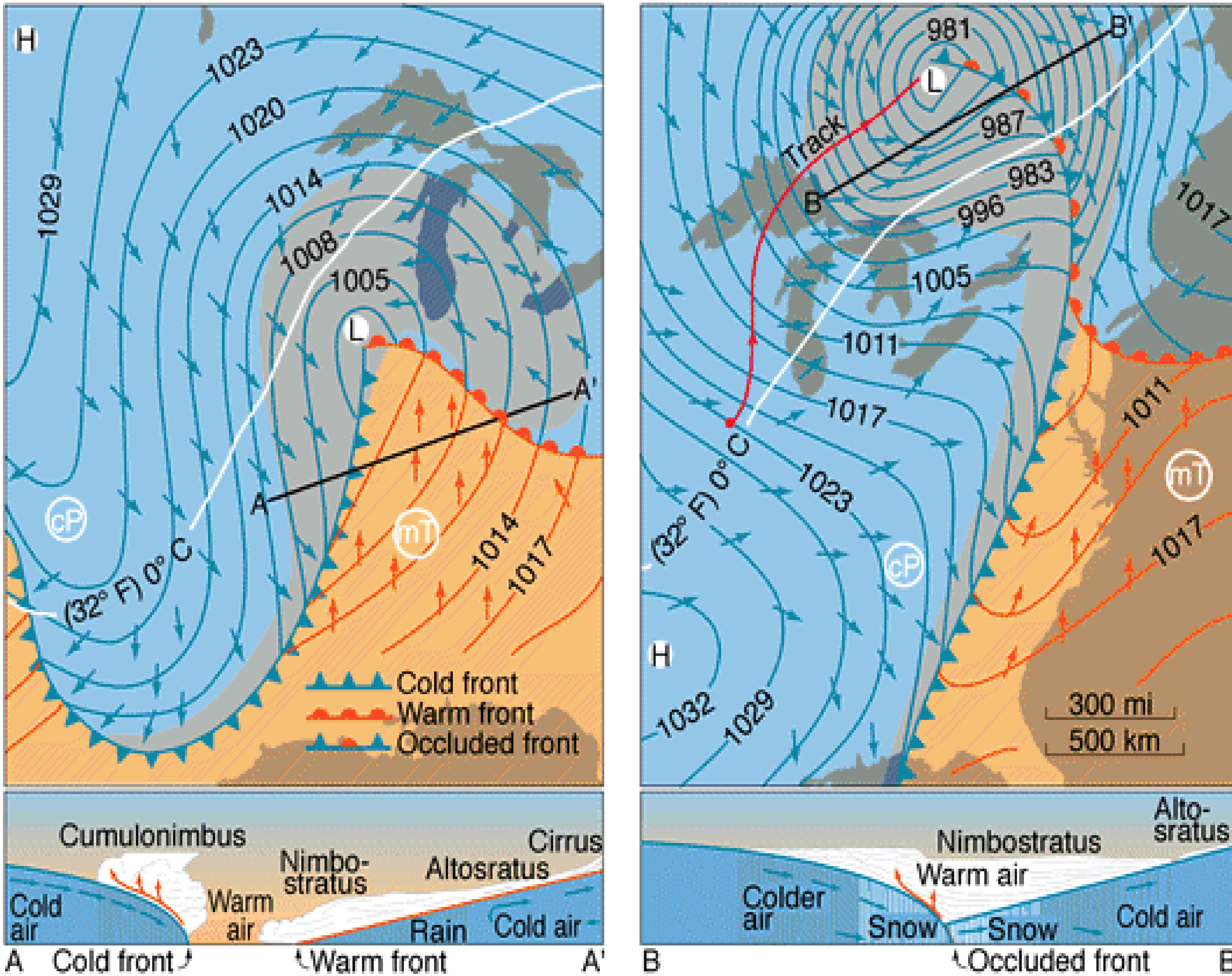

L
Warm sector


GVAR
[BRIT]
260
250
230
210
190
170
150
130
110
90
70
50
30
10
0011 G-8 IMG 01 31 MAR 98090 161500 02849 09125 08.00

3. Occluded Stage



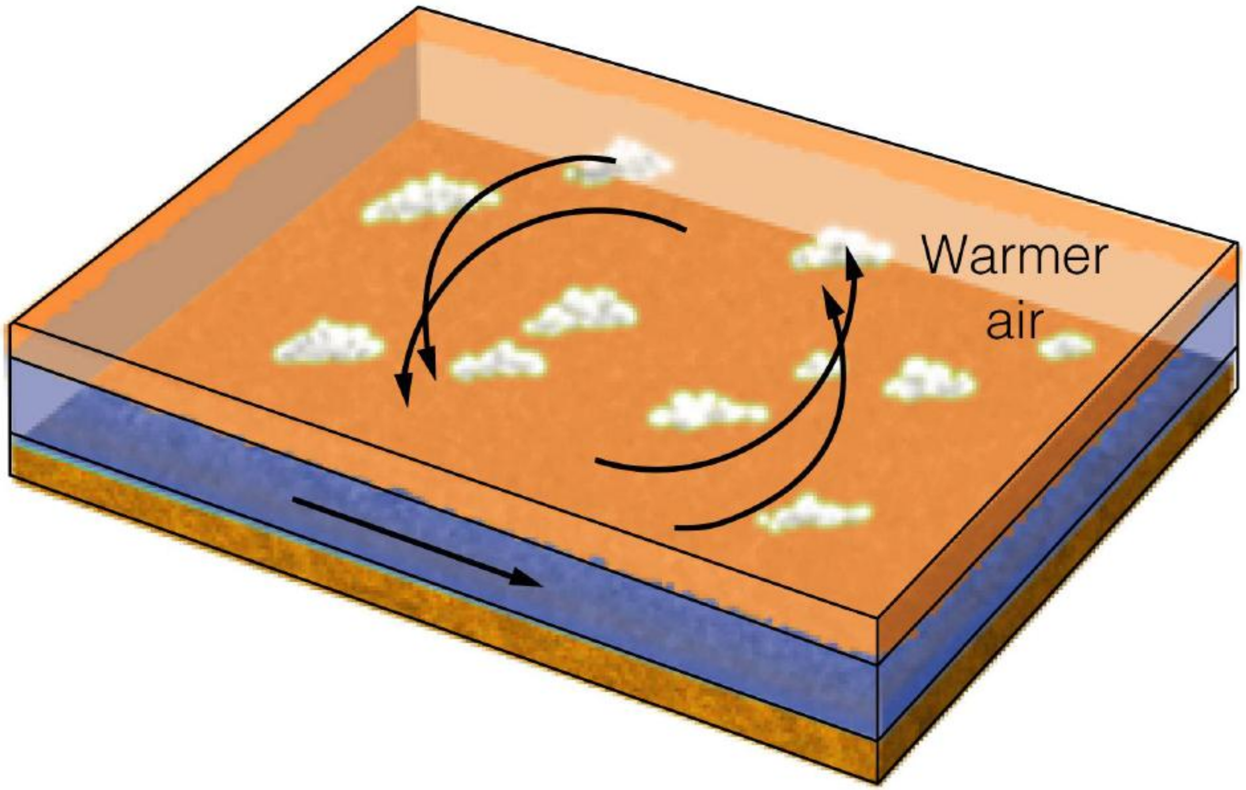

L



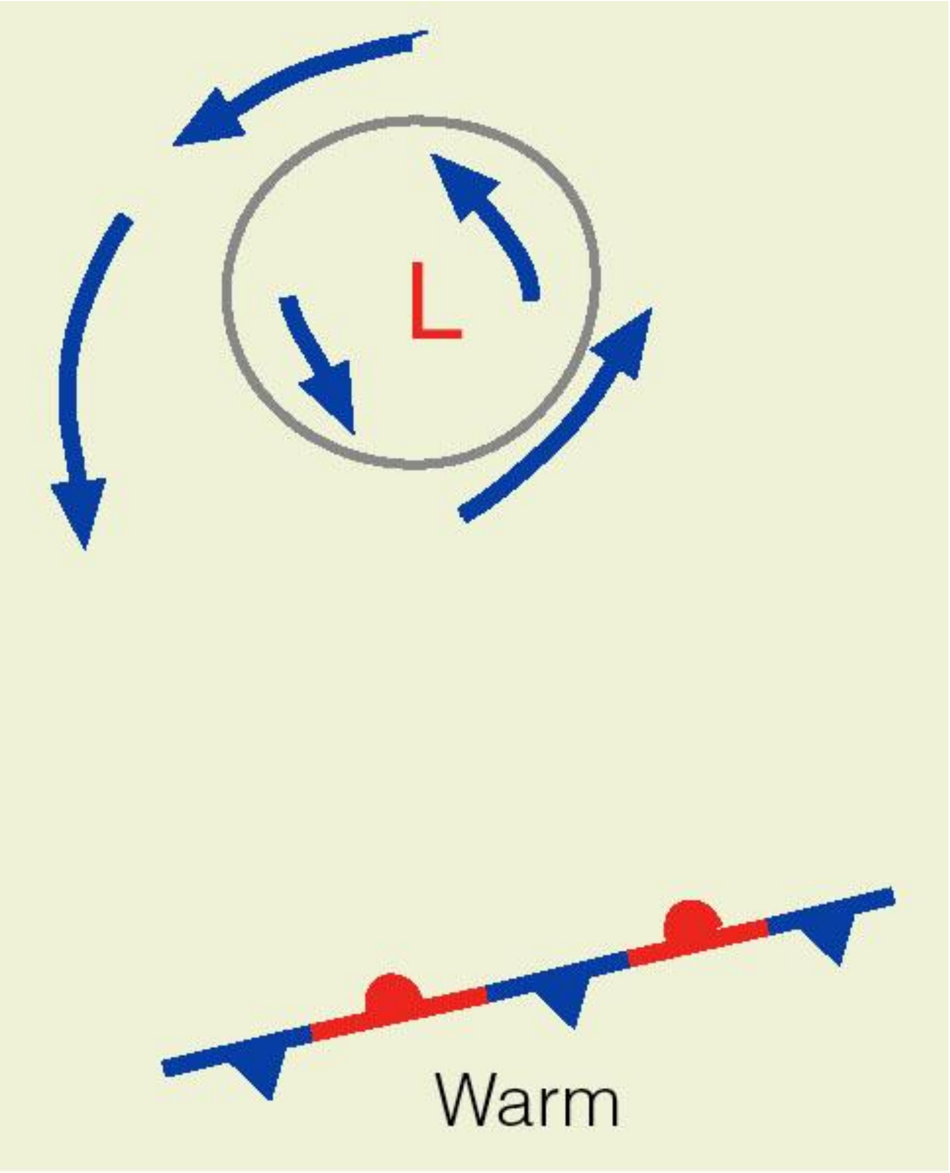
H
1023
1020
1014
1008
1005
1029
L
A
A'
cP
mT
(32° F) 0° C
1014
1017
Cold front
Warm front
Occluded front
981
B'
L
Track
987
983
B
996
1017
1005
1011
1017
C
1023
(32° F) 0° C
cP
1011
mT
1017
H
1032
1029
300 mi
500 km
Cumulonimbus
Cirrus
Nimbo-
stratus
Altosratus
Cold
air
Warm
air
Rain
Cold air
A
Cold front
Warm front
A'
Alto-
sratus
Nimbostratus
Warm air
Colder
air
Snow
Snow
Cold air
B
Occluded front
B'

4. Dissolving Stage

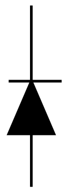
warm air mass completely cut off from ground; no more uplift



(d) Dissolving stage


L
Warm

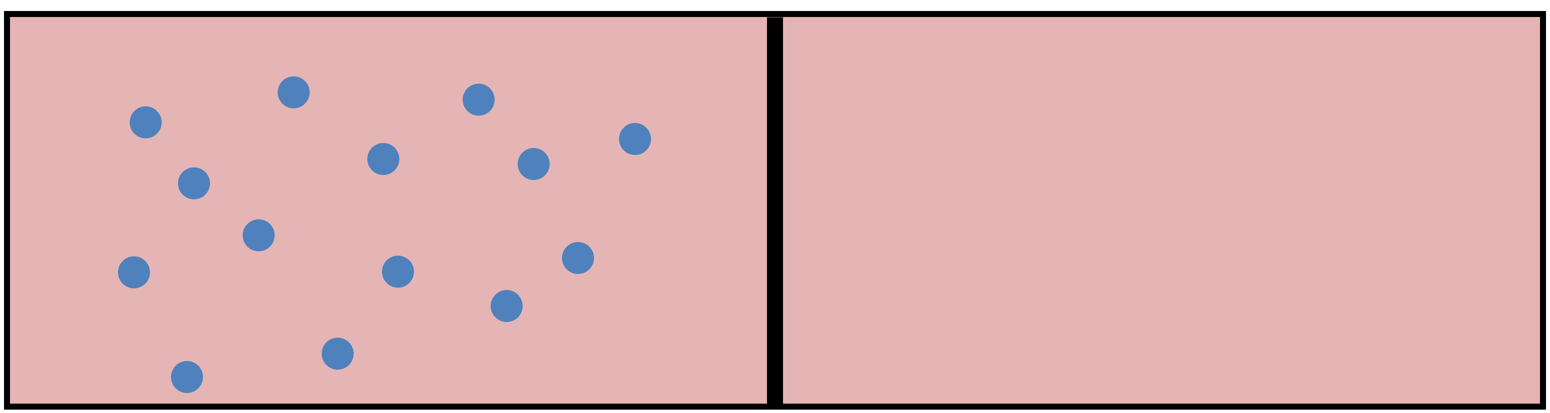
UNIT-III
SOLAR CELLS, PHOTOVOLATIC CELLS BASICS



PN Junctions

Diffusion

- Diffusion occurs when there exists a concentration gradient
- In the figure below, imagine that we fill the left chamber with a gas at temperate *T*
- If we suddenly remove the divider, what happens?
- The gas will fill the entire volume of the new chamber. How does this occur?

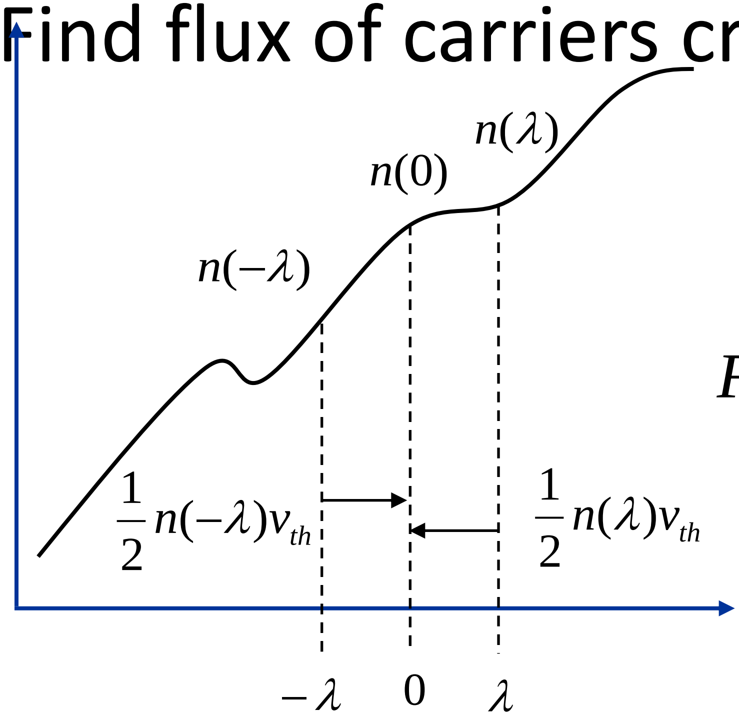


Diffusion

- The net motion of gas molecules to the right chamber was due to the concentration gradient
- If each particle moves on average left or right then eventually half will be in the right chamber
- If the molecules were charged (or electrons), then there would be a net current flow
- The diffusion current flows from high concentration to low concentration:

Diffusion Equations

- Assume that the mean free path is λ
- Find flux of carriers crossing x=0 plane



$$F = \frac{1}{2}v_{th}\left(n(-\lambda) - n(\lambda)\right)$$

$$F = \frac{1}{2}v_{th}\left(\left[n(0) - \lambda\frac{dn}{dx}\right] - \left[n(0) + \lambda\frac{dn}{dx}\right]\right)$$

$$F = -v_{th}\lambda\frac{dn}{dx}$$

$$J = -qF = qv_{th}\lambda\frac{dn}{dx}$$

Einstein Relation

- The thermal velocity is given by *kT*

$$\tfrac{1}{2} m_n^* v_{th}^2 = \tfrac{1}{2} kT$$

Mean Free Time

$$\lambda = v_{th} \tau_c$$

$$v_{th}\lambda = v_{th}^2 \tau_c = kT \frac{\tau_c}{m_n^*} = \frac{kT}{q} \frac{q\tau_c}{m_n^*}$$

$$J = q v_{th} \lambda \frac{dn}{dx} = q\left(\frac{kT}{q} \mu_n\right) \frac{dn}{dx}$$

$$D_n = \left(\frac{kT}{q}\right) \mu_n$$

Total Current and Boundary Conditions

- When both drift and diffusion are present, the total current is given by the sum:

$$J = J_{drift} + J_{diff} = q\mu_n nE + qD_n \frac{dn}{dx}$$

- In resistors, the carrier is approximately uniform and the second term is nearly zero
- For currents flowing uniformly through an interface (no charge accumulation), the field is discontinous

$J_1 \; (\sigma_1)$

$$J_1 = J_2$$

$$\sigma_1 E_1 = \sigma_2 E_2$$

$$\frac{E_1}{E_2} = \frac{\sigma_2}{\sigma_1}$$

Carrier Concentration and Potential

- In thermal equilibrium, there are no external fields and we thus expect the electron and hole current densities to be zero:

$$J_n = 0 = qn_0\mu_n E_0 + qD_n \frac{dn_o}{dx}$$

$$\frac{dn_o}{dx} = -\left(\frac{\mu_n}{D_n}\right) n_o E_0 = \left(\frac{q}{kT}\right) n_o \frac{d\phi_0}{dx}$$

$$d\phi_0 = \left(\frac{kT}{q}\right) \frac{dn_o}{n_0} = V_{th} \frac{dn_0}{n_0}$$

Carrier Concentration and Potential (2)

- We have an equation relating the potential to the carrier concentration

$$d\phi_0 = \left(\frac{kT}{q}\right)\frac{dn_o}{n_0} = V_{th}\,\frac{dn_0}{n_0}$$

- If we integrate the above equation we have

$$\phi_0(x) - \phi_0(x_0) = V_{th}\ln\frac{n_0(x)}{n_0(x_0)}$$

- We define the potential reference to be intrinsic Si:

$$\phi_0(x_0) = 0 \qquad n_0(x_0) = n_i$$

Carrier Concentration Versus Potential

- The carrier concentration is thus a function of potential $n_0(x) = n_i e^{\phi_0(x)/V_{th}}$

- Check that for zero potential, we have intrinsic carrier concentration (reference).
- If we do a similar calculation for holes, we arrive at a similar equation $p_0(x) = n_i e^{-\phi_0(x)/V_{th}}$

- Note that the law of mass action is upheld

$$n_0(x)\, p_0(x) = n_i^2 e^{-\phi_0(x)/V_{th}} e^{\phi_0(x)/V_{th}} = n_i^2$$

The Doping Changes Potential

- Due to the log nature of the potential, the potential changes linearly for exponential increase in doping:

$$\phi_0(x) = V_{th} \ln \frac{n_0(x)}{n_i(x_0)} = 26\text{mV } \ln \frac{n_0(x)}{n_i(x_0)} \approx 26\text{mV } \ln 10 \log \frac{n_0(x)}{10^{10}}$$

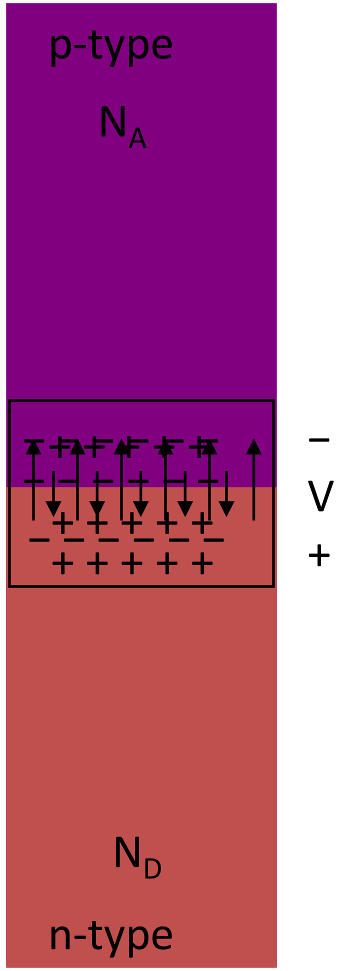
$$\phi_0(x) \approx 60\text{mV } \log \frac{n_0(x)}{10^{10}}$$

$$\phi_0(x) \approx -60\text{mV } \log \frac{p_0(x)}{10^{10}}$$

- Quick calculation aid: For a p-type concentration of 10^{16} cm^{-3}, the potential is -360 mV
- N-type materials have a positive potential with respect to intrinsic Si

PN Junctions: Overview

- The most important device is a junction between a p-type region and an n-type region
- When the junction is first formed, due to the concentration gradient, mobile charges transfer near junction
- Electrons leave n-type region and holes leave p-type region
- These mobile carriers become minority carriers in new region (can't penetrate far due to recombination)
- Due to charge transfer, a voltage difference occurs between regions
- This creates a field at the junction that causes drift currents to oppose the diffusion current
- In thermal equilibrium, drift current and diffusion must balance



PN Junction Currents

- Consider the PN junction in thermal equilibrium
- Again, the currents have to be zero, so we have

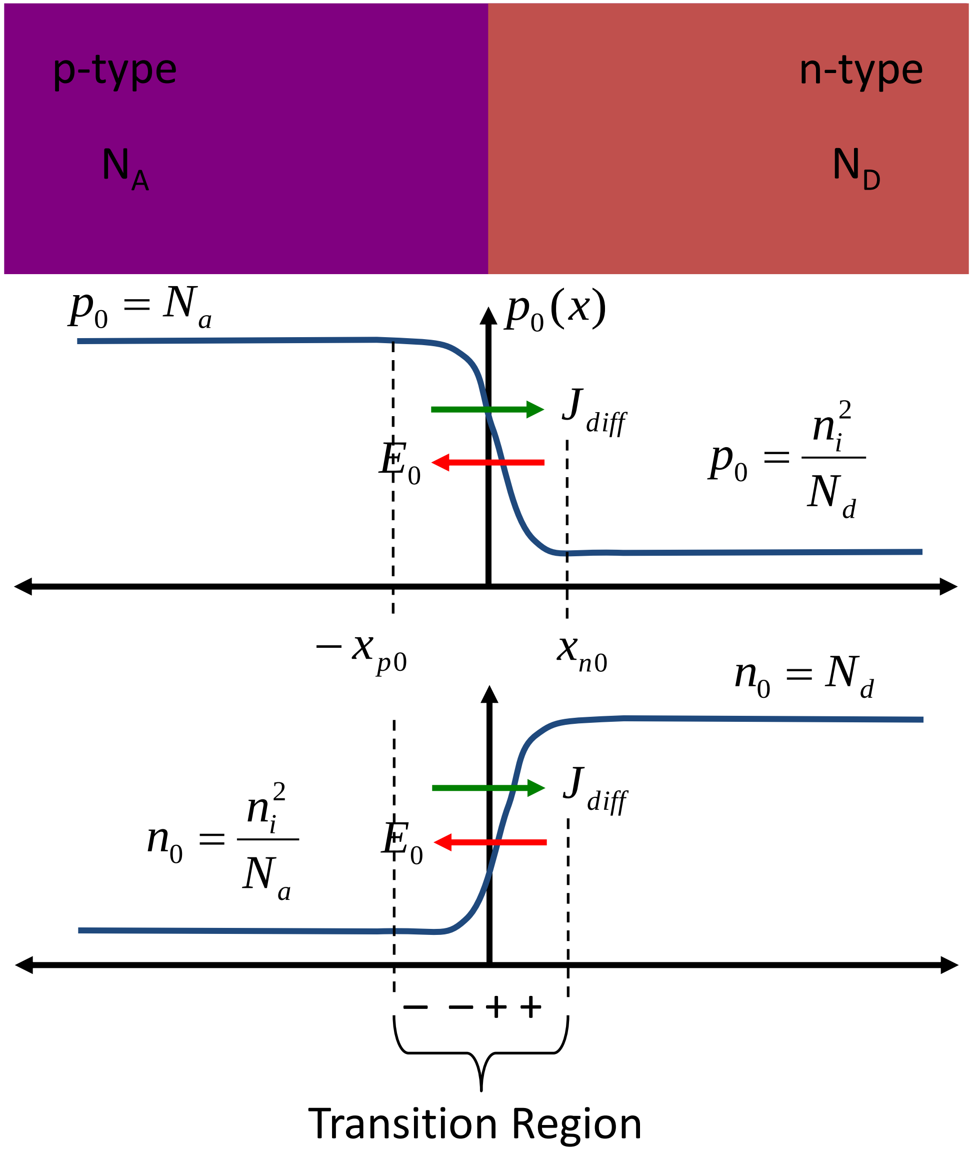
$$J_n = 0 = qn_0\mu_n E_0 + qD_n \frac{dn_o}{dx}$$

$$qn_0\mu_n E_0 = -qD_n \frac{dn_o}{dx}$$

$$E_0 = \frac{-D_n \frac{dn_o}{dx}}{n_0\mu_n} = -\frac{kT}{q}\frac{1}{n_0}\frac{dn_0}{dx}$$

$$E_0 = \frac{D_p \frac{dp_o}{dx}}{n_0\mu_p} = -\frac{kT}{q}\frac{1}{p_0}\frac{dp_0}{dx}$$

PN Junction Fields



UNIT-IV

SOLAR ENERGY

Solar Radiation Measurement:

- Measurement of solar radiation is the most important aspect for study of Quantum of Energy.
- Generally, 3 types of instruments are used:

I. Pyranometer.
II. Pyrheliometer.
III. Sunshine recorder.

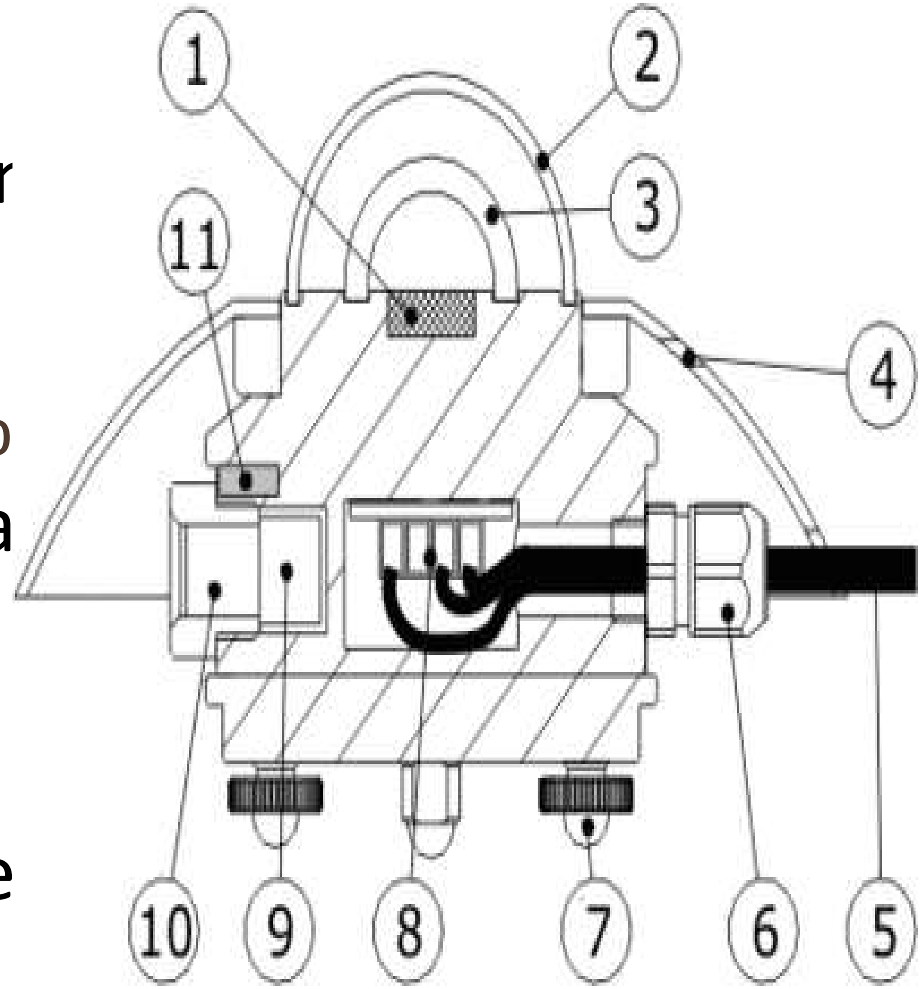
PYRANOMETER

- The name Pyranometer is derived from Greek word “pyr” means “fire” and “ano” means “above, sky”.
- It is a type of instrument to measure broadband solar irradiance on planar

MAIN COMPONENTS

- ✖ Black Surface:
  - ✓ Receives the beam ar temperature rises.
- ✖ Glass Dome:
  - ✓ Prevents loss of radia
- ✖ Thermopile:
  - ✓ Temperature sensor.
  - ✓ No. of Thermocouple sensitivity.

o



APPLICATIONS

- Pyranometers are frequently used in:
- Meteorology
- Climatology
- Solar energy study
- Building Physics.

PYRHELIOMETER

- A pyrheliometer is an instrument for measurement of direct solar irradiance.
- It is used with a solar tracking system to keep the instrument aimed at Sun.
- Pyrheliometer is often used with same setup of Pyranometer.

pyrhel

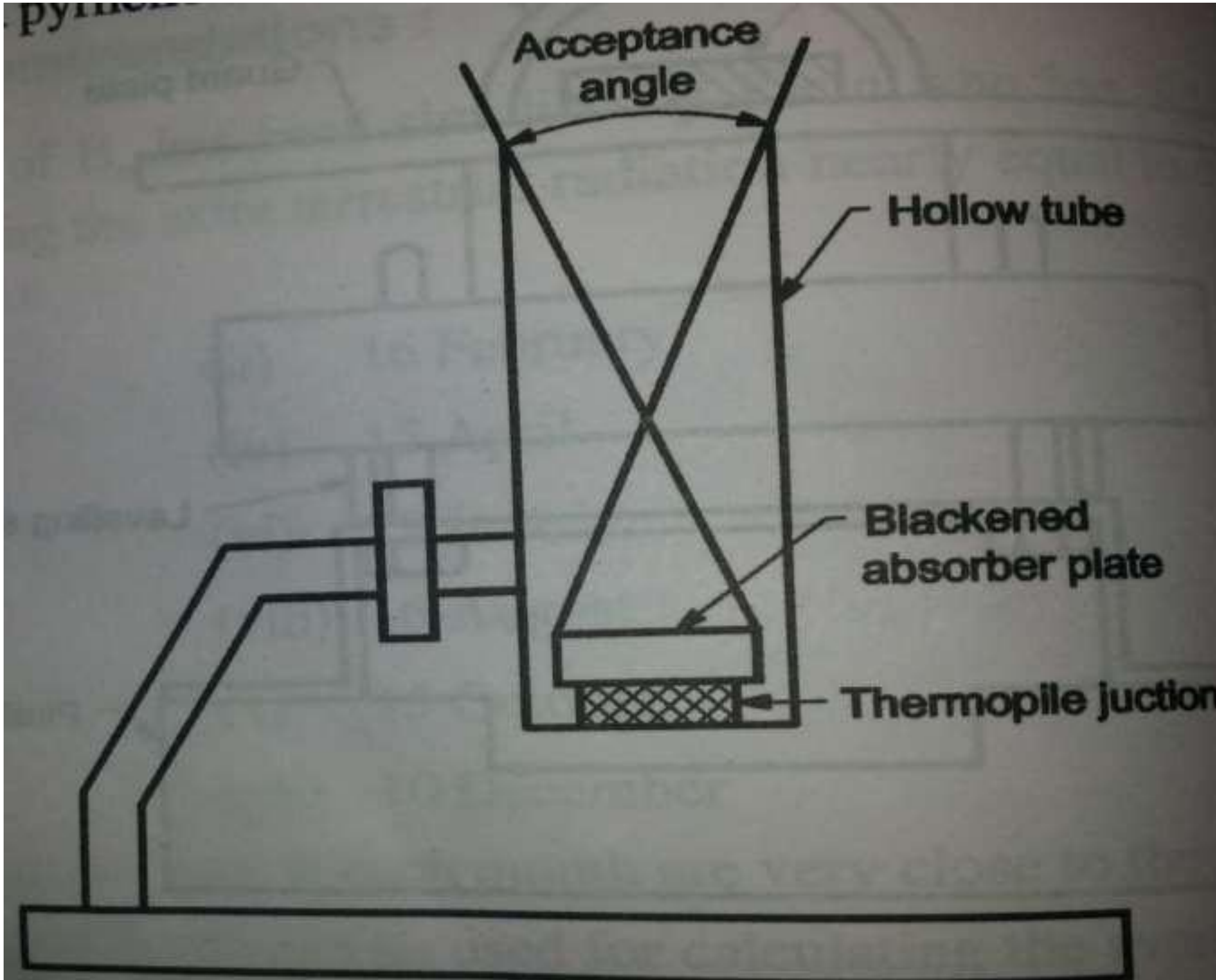


Fig. 2.9.2 : Pyrheliometer

MAJOR COMPONENTS

- Receiver:
  - ✓ Shape of Hollow tube with reflecting surface inside.
- Absorber plate:
  - ✓ Consists of Black end plate
  - ✓ Placed at bottom of tube
- Thermopile:
  - ✓ Sensing element of temperature

SUNSHINE RECORDER

- This instrument is used to measure the hours of Bright Sunshine in a day.

SUNSHINE RECORDER

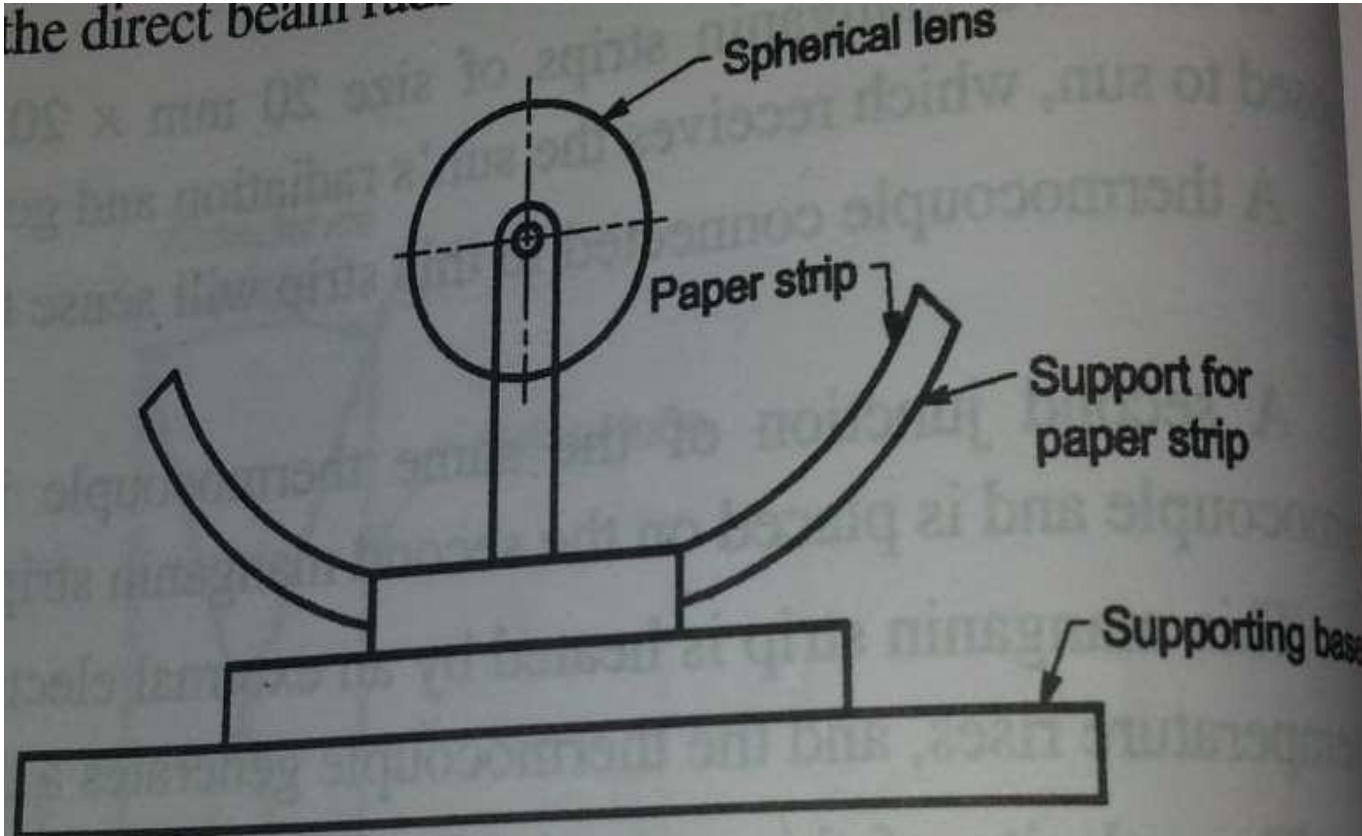


Fig. 2.9.4 : Sunshine recorder

UNIT-V

CONCENTRATION OF SOLAR ENERGY , ENERGY STORAGE

Contents

- Battery is nothing but a device which converts stored chemical energy in electrical energy.
- A rechargeable battery or secondary battery is a type of electrical battery which can be charged, discharged into a load, and recharged many times.

- Battery is nothing but a device which converts stored chemical energy in electrical energy.
- A rechargeable battery or secondary battery is a type of electrical battery which can be charged, discharged into a load, and recharged many times.

Why Do We Need Batteries?

Everything from the starter to the radio of such machines may be powered by one or more Heavy-duty batteries.

- ❖ The most accessible place for batteries to be used is around the house. Disposable batteries tend to power things like remote controls, flashlights, hearing aids, and weight scales.
- ❖ Rechargeable batteries tend to be found powering digital cameras, handheld video game consoles, remote-controlled cars, home-maintenance tools, and more.

- More advanced batteries, such as lithium batteries, are instrumental in providing power to laptops and other devices.
- Hospitals and emergency services both depend upon batteries for everything from pacemakers to defibrillators.
- The importance of batteries in military environments in certain types of optical equipment such as night vision apparatuses, and the various tools that make their field work safe.
- Insulin pumps, valve-assistance devices, and other types of cutting-edge technology designed to

  improve a person’s life tend to use batteries.

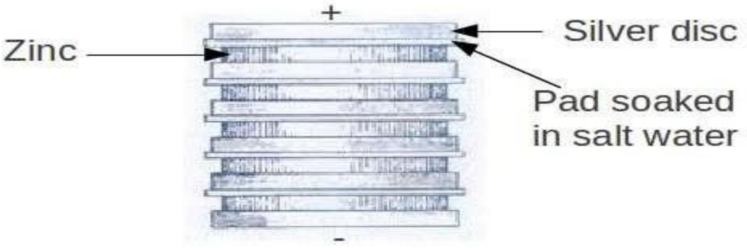
Brief History About Batteries

- Benjamin Franklin – 6th President of Pennsylvania.
- In 1749, Benjamin Franklin first used the term "battery" to describe a set of linked capacitors he used for his experiments with electricity.
- In 1750 He published a proposal for an experiment to prove that lightning is electricity by flying a kite in a storm.
- In 10th May, 1752 a French Scientist conducted his experiment using a 40ft tall iron rod instead of a kite and he extracted electrical sparks from cloud.

- However a fellow scientist disagreed believing this phenomenon caused by two different metals joined together by a moist intermediate.
- He verified this hypothesis through experiment and published the results in 1791.
- In 1800 Volta invented the first battery which came to be known as voltaic pile.
- The voltaic pile consist of pairs of copper &zinc

discs piled on the top of each other, separated by a layer of cloth soaked in brine (electrolyte).

- He experiment with different metals and found that zinc and silver gave the best results.



❖1800	Voltaic Pile: Silver Zinc
❖1836	Daniell Cell: Copper Zinc
❖1859	Planté: Rechargeable Lead-acid Cell Leclanché: Carbon
❖1868	Zinc Wet Cell Gassner: Carbon Zinc Dry Cell
❖1888	Commercial Flashlight, D Cell Junger: Nickel
❖1898	Cadmium Cell Neumann: Sealed Ni-Cd
❖1899	Alkaline, Rechargeable Ni-Cd Lithium, Sealed
❖1946	Lead Acid Nickel metal hydride (NiMH) Lithium
❖1960	ion
❖1970	Rechargeable alkaline Lithium ion
❖1990	polymer

Types Of Battery

Basically batteries can be classified as two types as

primary batteries and secondary batteries.

- **Primary Battery(disposable)**

- In primary batteries, the electrochemical reaction is not reversible.
- Used when long periods of storage are required.
- During discharging the chemical compounds are permanently changed and electrical energy is released until the original compounds are completely exhausted.
- Lower discharge rate than secondary batteries.
- Thus the cells can be used only once.

- **Some Examples Of Primary Batteries**

1. **Zinc Carbon** – Used in flashlights, toys
2. **Heavy Duty Zinc Chloride** – Used in radios, recorders
3. **Alkaline** – Used in all of the above
4. **Lithium** – Used in photoflash
5. **Silver Mercury Oxide** – Used in Hearing aid, watches, calculators

2. **<u>Heavy Duty Zinc Chloride</u>** – Used in radios, recorders

3. **<u>Alkaline</u>** – Used in all of the above

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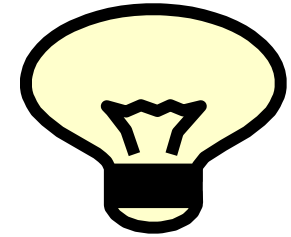

Zinc Carbon Battery

- Zinc (-ve electrode), Carbon(+ve electrode)
- Ammonium Chloride paste as electrolyte.
- Carbon is only a practical electrode. In cell reactions we consider MnO_2 as cathode.
- Here powdered carbon and MnO_2 prevents the formation of H_2 Gas on cathode, which would stop the cell from working normally.
- This kind of batteries is generally used in flashlights and toys.

$\longrightarrow Zn^{+2}{}_{(aq)} + 2e^-$

<u>Cell Reaction</u>

- <u>On anode (-ve electrode)</u> $\longrightarrow$ $Mn_2O_{3(s)} + 2NH_{3(aq)} + H_2O_{(l)} + 2Cl^-{}_{(aq)}$

Features

- ❖ Inexpensive, widely available.
- ❖ Inefficient at high current drain.
- ❖ Poor discharge curve (sloping).
- ❖ Poor performance at low temperatures.

➢ In 2016 a design employing MnO_2 coated goldnanowires and a PMMA gel electrolyte lasted 2 Lakh cycles over three months without fracturing any nanowire.

Heavy Duty Zinc Chloride Batteries

- ❖ Zinc (-ve electrode), MnO_2(+ve electrode)
- ❖ Zinc Chloride paste as electrolyte.
- ❖ Here powdered carbon and MnO_2 prevents the formation of H_2 Gas on cathode, which would stop the cell from working normally.
- ❖ This kind of batteries is generally used in radios and recorders.

<u>Features (compared to Zinc Carbon)</u>

- ❖ Better resistance to leakage.
- ❖ Better at high current drain.

❖ Better performance at low temperature.

Alkaline Batteries

❖ Zinc (-ve electrode), MnO_2(+ve electrode)

❖ Potassium Hydroxide paste used as electrolyte.

❖ Here powdered carbon and MnO_2 prevents the formation of H_2 Gas on cathode, which would stop the cell from working normally.

❖ This kind of batteries is generally used in toys, flashlights, radios and recorders.

Features

- ❖ 50-100% more energy than carbon zinc
- ❖ Low self-discharge (10 year shelf life)
- ❖ Good for low current (< 400mA), long-life use
- ❖ Poor discharge curve

➢ **Secondary Battery(Rechargeable)**

- ❖ In secondary batteries, the electrochemical reaction is reversible.
- ❖ Used when short periods of storage are required.
- ❖ During discharging the chemical compounds which are changed can be reconstituted by the application of an electrical potential between the electrodes.
- ❖ Higher discharge rate than primary batteries.
- ❖ Thus such cells can be Rechargeable and used many times.

2. Nickel Metal Hydride Battery

3. Lead Acid Battery

4. Lithium Ion Battery

Nickel Cadmium Batteries

- ❖ Cadmium (-ve), Nickel Hydroxide (+ve)
- ❖ Potassium Hydroxide aqueous used as an electrolyte.

Cell Reaction

- ❖ On anode (-ve electrode)

$$Cd + 2OH^- \quad Cd(OH)_2 + 2e^-$$

❖ On cathode (-ve electrode)

$$2NiO(OH)+Cd+2e^{-} \longrightarrow 2Ni(OH)_2+2OH^{-}$$

Advantages Of Ni-Cd Batteries

❖ Available in different size and shapes.

❖ Have ability to deliver full power output until end of cycle

❖ Very low internal resistance

- Simple and fast to recharge Over 1000 cycles (if properly maintained)
- Operate in a range of temperatures.
- Tolerates abuse well and performs well after long periods of storage.

Disadvantages Of Ni-Cd Batteries

- It is three to five times more expensive than lead- acid.
- Self-discharge up to 10% in a day.
- Its materials are toxic and the recycling infrastructure for larger nickel-cadmium batteries is very limited.

Uses Of Ni-Cd Battery

- Ni-Cd batteries may be used individually or assembled into battery packs containing two or more cells.
- Especially Ni-Cd batteries are used in cordless and wireless telephones, emergency lighting and other applications.
- With a low internal resistance, they can supply a high surge current. This makes them a favourable choice for remote controlled model airplanes, boats, cars and camera flash units.

Lithium Ion Battery

- ❖Graphite (-ve), Lithium cobalt dioxide (+ve)
- ❖Non aqueous electrolyte

Cell Reaction

❖On anode (-ve electrode)

$$6C + Li^{+} + e \rightleftharpoons LiC_6$$

❖On cathode (-ve electrode)

$$LiCoO_2 \qquad Li_{0.5}CoO_2 + Li^{+} + e^{-}$$

Advantages Of Lithium Ion Battery

- ❖The most distinct advantage is high energy density.
- ❖Lower self-discharge rate.
- ❖No maintenance. No memory effect.

❖ No requirement for priming.

❖ Variety of types available.

Disadvantages Of Lithium Ion Battery

❖ Require protection from overcharge &fully discharge.

❖ Shows ageing.

❖ Transportation by air is sometimes difficult.

❖ 40% more costly than Ni-Cd batteries.

❖ No established system for recycling large lithium- ion batteries.

Uses Of Lithium Ion Batteries

What If We Use Conducting Polymers In Batteries

<u>Advantages</u>

- Longer cyclic time
- high discharge time
- Less self-discharge time
- Flexible shape
- Easy fabrication of component in film form

<u>Disadvantage</u>

- **Cost**

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