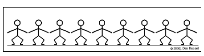
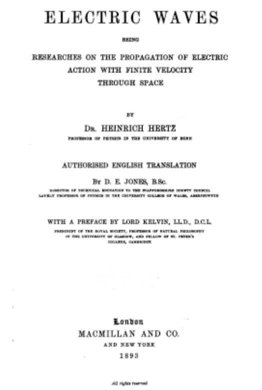
**LARC BASIC AMATEUR RADIO COURSE - 2017**

## WAVES and PROPAGATION

**Mike Cook© VE3ZMC**





ELECTRIC WAVES

BEING

RESEARCHES ON THE PROPAGATION OF ELECTRIC ACTION WITH FINITE VELOCITY THROUGH SPACE

BY

DR. HEINRICH HERTZ

AUTHORISED ENGLISH TRANSLATION

BY D. E. JONES, B.Sc.

WITH A PREFACE BY LORD KELVIN, LL.D., D.C.L.

London

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1893

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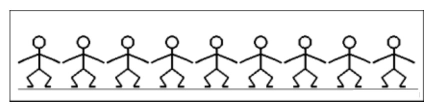
$$\nabla \bullet \varepsilon \mathbf{E} = \rho$$

$$\nabla \bullet \mu \mathbf{H} = 0$$

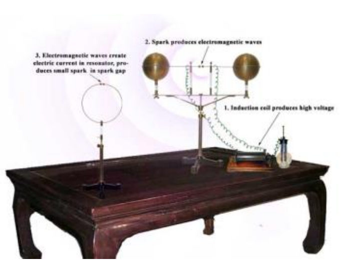
$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

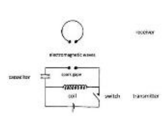

James Clark Maxwell

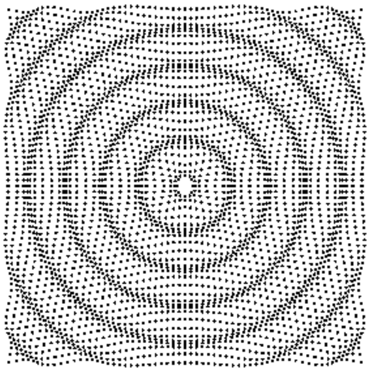


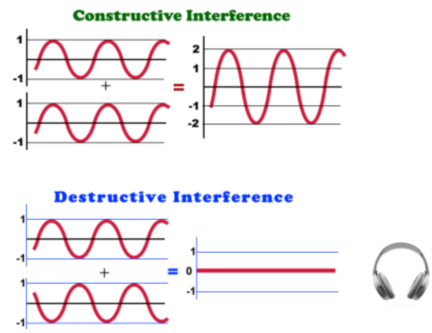
**What is a wave?**

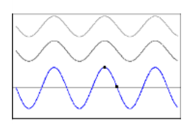



Heinrich Hertz

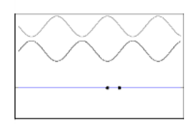






Travelling Wave

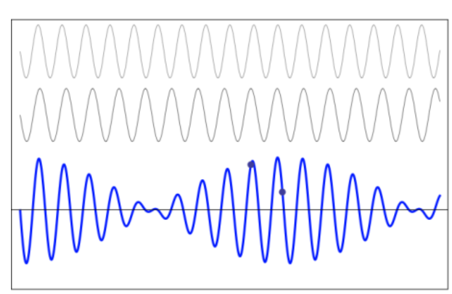


Standing Wave

Diagrams by Dan Russell

**Waves can interact with each other**

***Destructive and constructive interference***



Beat frequency

Diagram by Dan Russell

Waves can be reflected



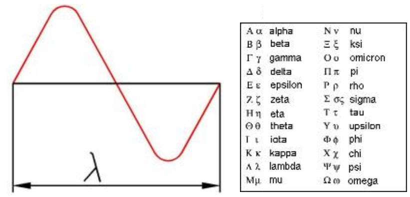



Fig 5-4

Wavelength

e.g. λ = 2 meters

Waves enc


esistance)

Standing \
*more abou*

*much*

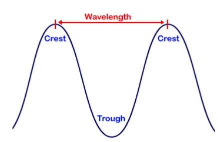



Diagram by Dan Russell

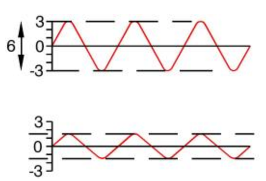
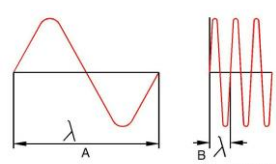



Fig 5-1

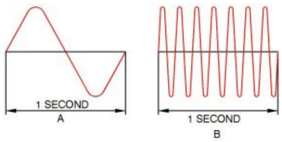
Amplitude




λ

Fig 5-5

½ ¼



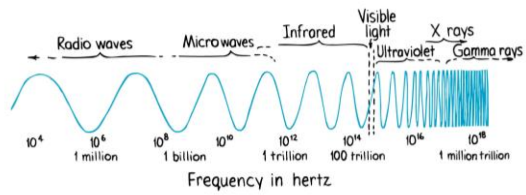

f

Fig 5-3

Frequency
f = 1 Hz

Frequency
f = 7 Hz

1,000 Hz = 1 kHz
1,000,000 Hz = 1 MHz




ENERGY

**Scientific Notation**

1,000 Hz = 1 kHz ($10^3$)
1,000,000 Hz = 1 MHz ($10^6$)

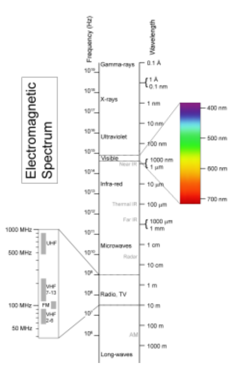
eg. 1,000,000 — Decimal point moves 6 places to the right

1.0

$10^{-6}$
0.000001 — Decimal point moves 6 places to the left

1.0 / Orders

| | |
|---|---|
| 0.003 MHz | |
| | Very Low Frequency (VLF) |
| 0.03 MHz | |
| | Low Frequency (LF) |
| 0.3 MHz | |
| | Medium Frequency (MF) |
| 3 MHz | |
| | High Frequency (HF) |
| 30 MHz | |
| | Very High Frequency (VHF) |
| 300 MHz | |
| | Ultra High Frequency (UHF) |
| 3 000 MHz | |
| | Super High Frequency (SHF) |
| 30 000 MHz | |
| | Extra High Frequency (EHF) |
| 300 000 MHz | |




EM waves

We need one other thing to describe a radio wave, its velocity.

C

C stands for *Celeritas*, latin for swiftness or speed.
*We use it now to stand for the speed of light*

It is also a Constant value – 300,000,000 m/s ($3x10^8$ m/s)
in a vacuum

1.25 sec

The relationship between wavelength, frequency and velocity is:

$$\lambda f = C$$

Wavelength x Frequency = Speed of light (C)

Wavelength = $\frac{\text{Speed of light}}{\text{Frequency}}$ $\lambda = \frac{C}{f}$

Frequency = $\frac{\text{Speed of light}}{\text{Wavelength}}$ $f = \frac{C}{\lambda}$

## Useful conversions

To convert kHz to MHz, divide by 1,000

1050 kHz = $\frac{1050}{1000}$ = 1.05 MHz

To convert MHz to kHz, multiply by 1000

14.10 MHz = 14.10 x 1000 = 14,100 kHz

Example calculations:

What is the frequency associated with the 80m band?

$f = \frac{C}{\lambda} = \frac{300}{80} = 3.75$ MHz

A transmitter operating at 146.5 MHz is using which band?

$\lambda = \frac{C}{f} = \frac{300}{146.5} = 2.05$ m

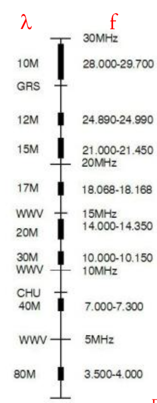


Fig 5-6

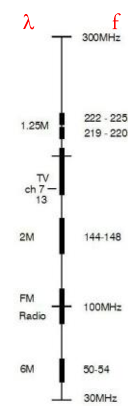


Fig 5-7

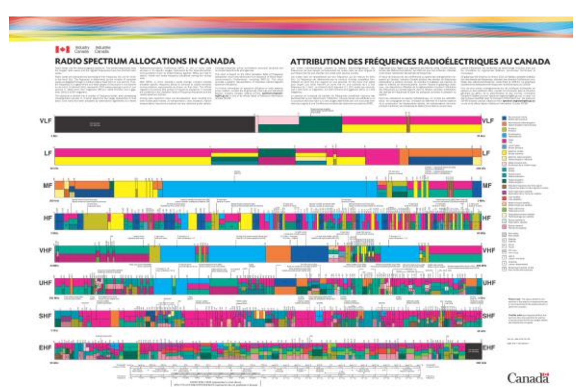
Example calculations:

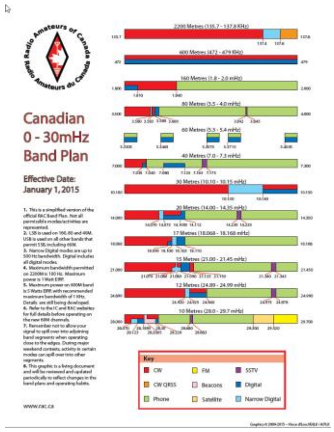
What is the frequency associated with the 80m band?

$f = \frac{C}{\lambda} = \frac{300}{80} = 3.75$ MHz

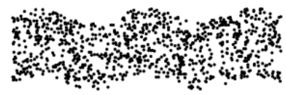
A transmitter operating at 146.5 MHz is using which band?

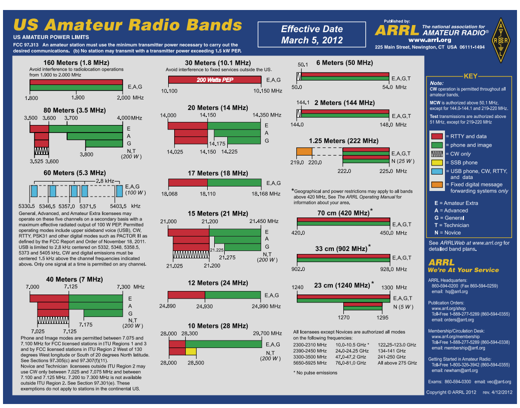
$\lambda = \frac{C}{f} = \frac{300}{146.5} = 2.05$ m






Waves can be longitudinal or transverse






What are radio waves?

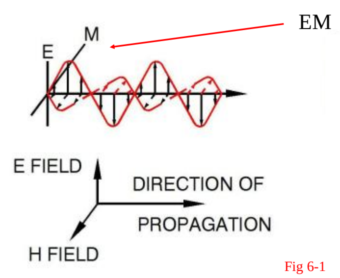
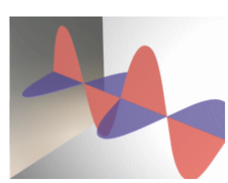
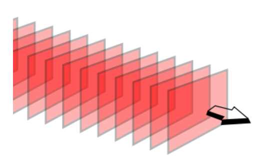
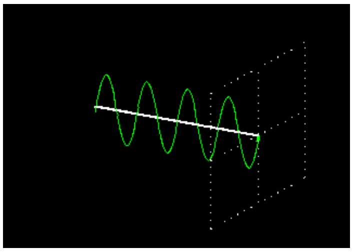


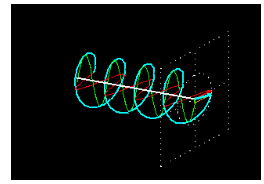

Fig 6-1

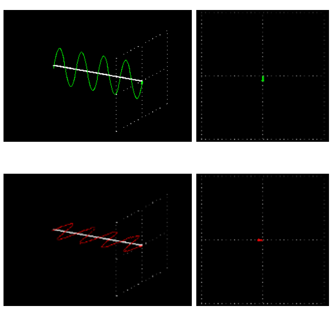




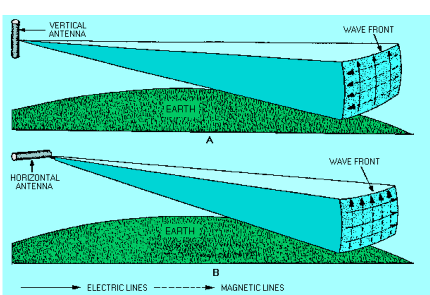


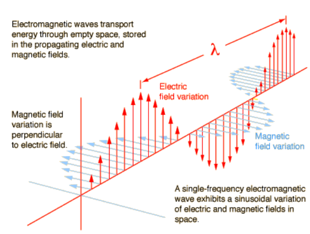
**Plane Waves**



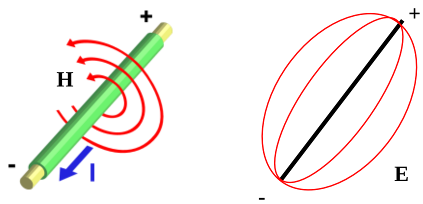


Polarization…. Use plane of E field



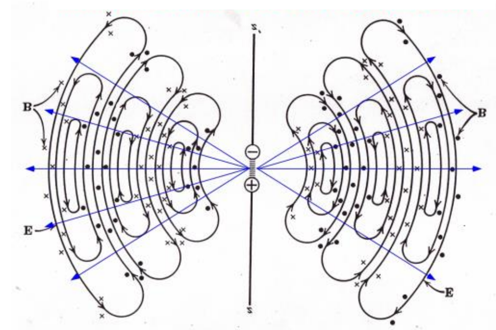



## So how do you make a radio wave?




E and H fields grow and collapse with each I reversal

When the f is high enough….

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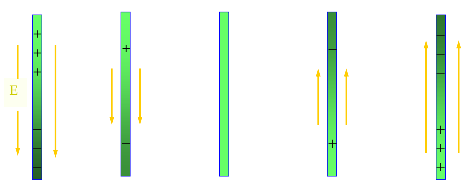
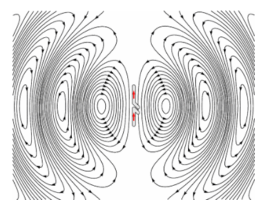
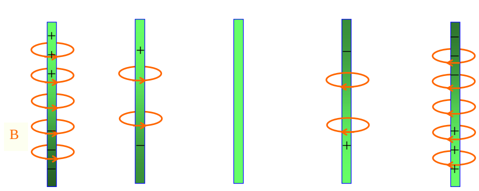
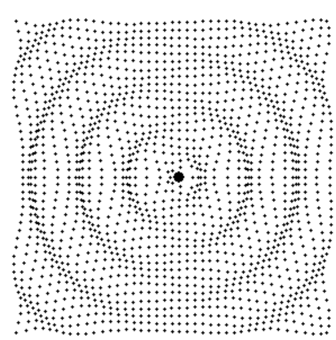


## So how do you make a radio wave?



$$\nabla \bullet \varepsilon \mathbf{E} = \rho$$
$$\nabla \bullet \mu \mathbf{H} = 0$$
$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

**A charged particle is a source of an electric field**

**When that particle moves it changes the (*spatial distribution of*) the electric field**

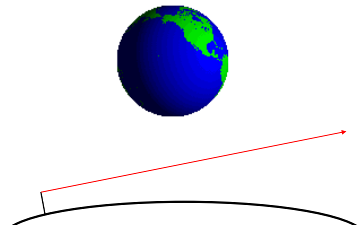
**When the electric field changes it produces a circulating magnetic field**

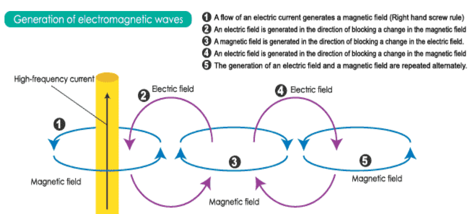
**If the particle accelerates, this circulating magnetic field will change**

**A changing magnetic field produces a circulating electric field**

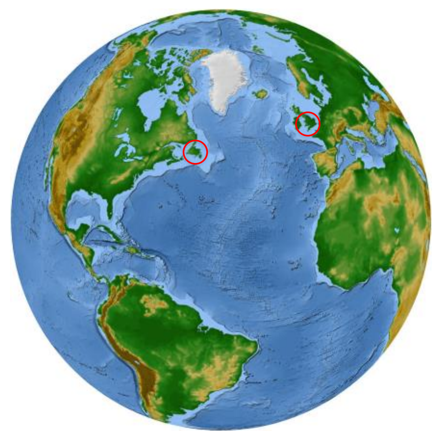
**The circulating electric field becomes the source of a circulating magnetic field**

EM waves travel in straight lines….
…unless acted on by outside forces.



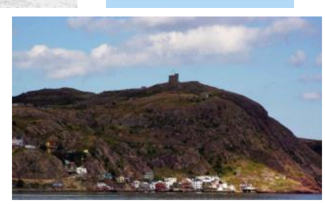



No medium is required



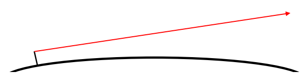
And now…….

**PROPAGATION**



**Marconi (1901) sent radio signal from Poldhu, Cornwall, UK, to St. Johns, Newfoundland.**

***Signal was Morse code letter "S"*** **. . .**



**How the signal got there was not understood at the time.**

**We now know about the ionosphere and its role in the propagation of radio waves**

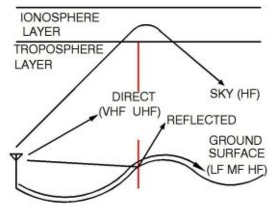




Fig 6-2

Tropospheric waves

Ionospheric waves

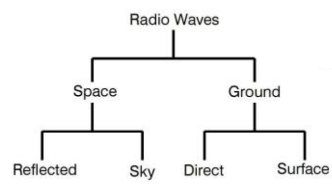
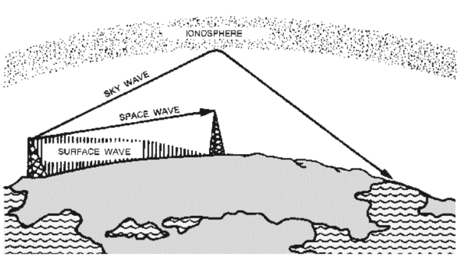




Fig 6-3

PROPAGATION




**Ground Waves are surface waves that propagate close to the surface of the Earth.**

**Ground waves (*or Direct Waves*) travel in straight lines (*line of sight*). These waves may be deviated or reflected by obstructions and cannot travel over the horizon or behind obstacles. Most common propagation mode at VHF and higher frequencies.**

**At higher frequencies and in lower levels of the atmosphere, any obstruction between the transmitting and receiving antenna will block the signal.**

**Space Waves travel directly from an antenna to another without reflection at the ground. Occurs when both antennas are within line of sight of each another. Distance is longer than line of sight because most space waves bend near the ground and follow practically a curved path.**

**Antennas must display a low angle of radiation so that power is radiated in direction of the horizon. A horizontally polarized antenna is most often used on the HF bands while VHF/UHF use vertical polarization.**

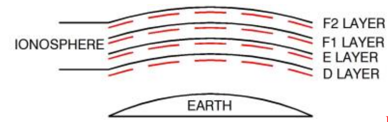


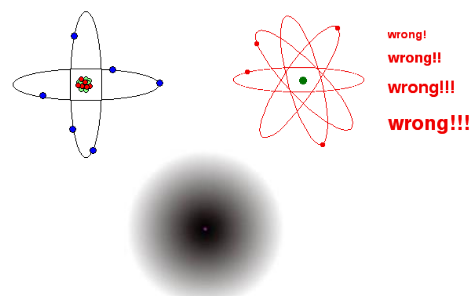

Fig 6-4

Structure of the ionosphere

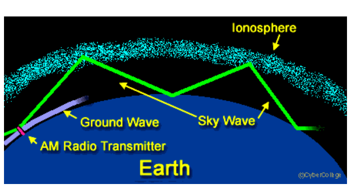
How does it arise?

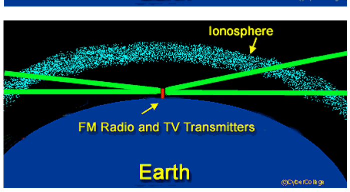
***We'll start with atoms***

**Sky Wave (*Skip/ Hop/ Ionospheric Wave*) is the propagation of radio waves refracted back to the Earth by the ionosphere. HF radio communication (between 3 and 30 MHz) is the result of skywave propagation.**

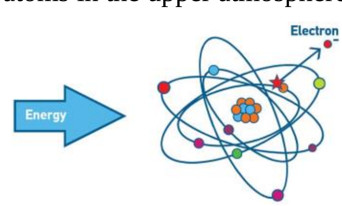



Atoms with an extra electron or a missing electron are known as ions



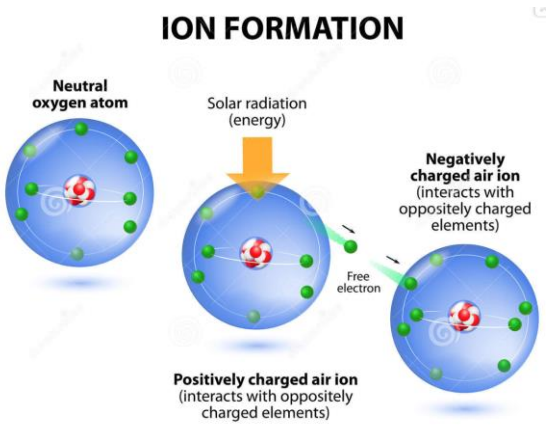



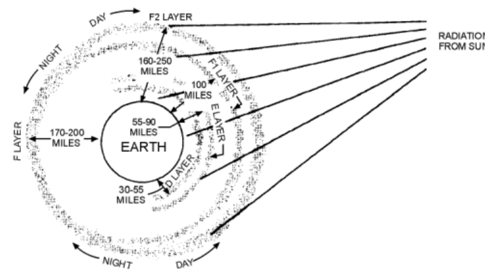

Solar radiation creates ions from the atoms in the upper atmosphere



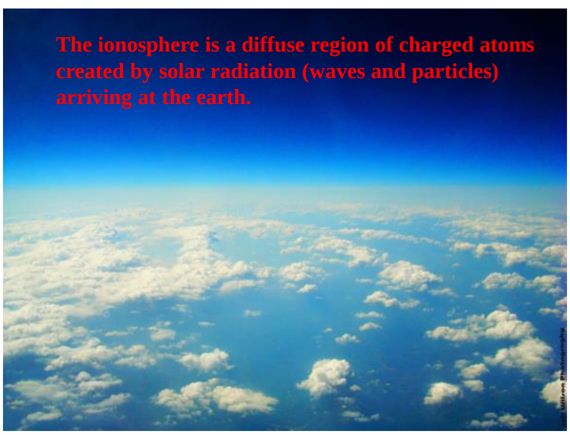

The atoms include: Oxygen, Nitrogen, Hydrogen and Helium

*Free electrons are also formed.* Dynamic




**NB: Not layers within which the earth rotates!**

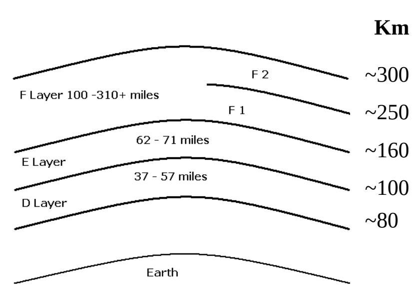


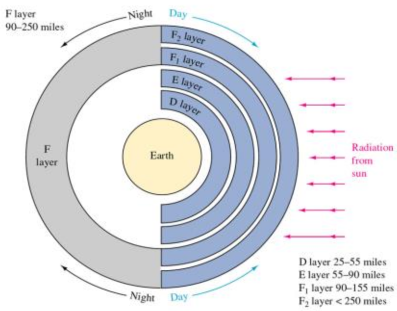

**The ionosphere is most ionized at midday and is least ionized just before dawn**

**The D layer is closest to the earth and absorbs radio waves, especially the lower frequencies. Least useful for DX** **(long distance communication)**

**The E layer refracts radio waves but is lower than the F layer(s). Some absorption too.** ***(Grey line)***

**The F layer splits into two sub-regions, F1 and F2, during the day. At night only a single F layer exists. It is the highest region of the ionosphere and by refracting waves is responsible for worldwide DX propagation**





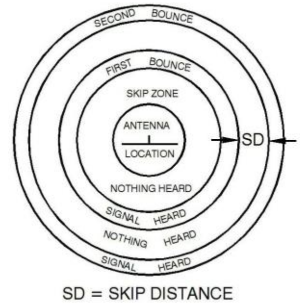
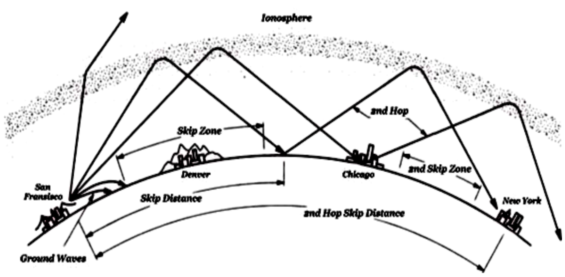
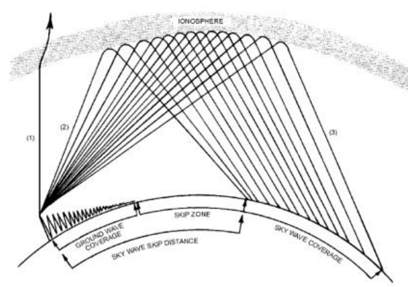



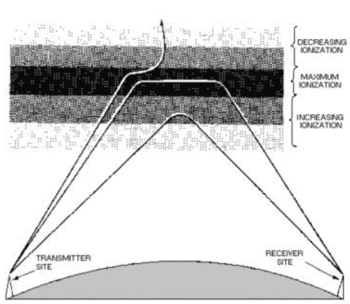

Fig 6-6



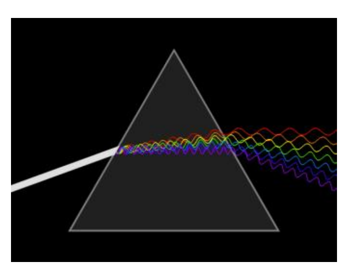

NB: Multi hop, refraction, reflection

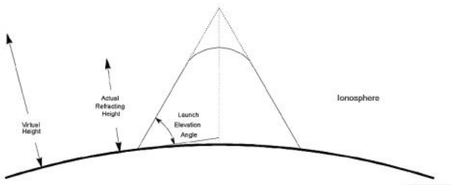



**∠ may change causing fading**




Refraction (not reflection) at the ionosphere






**Refraction is frequency- and angle-dependent**

f ∠

**Effects of solar activity on HF propagation are summarized on page 6.6, and Fig 6.7**

**Attenuation of radio waves** (Field strength)

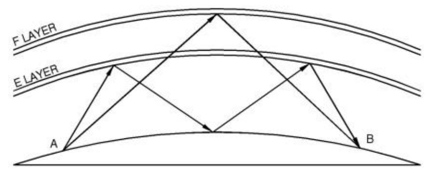
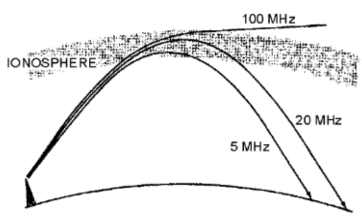



Fig 6-8




f-dependence

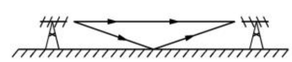
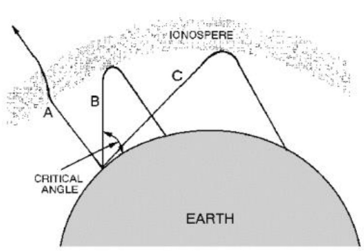


Fig 6-9

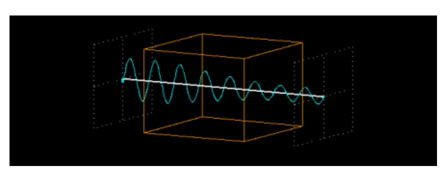
**Multiple signal paths contribute to fading**

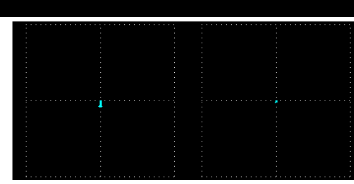
**The processes involved are absorption, phase shifting and changes in polarization.**

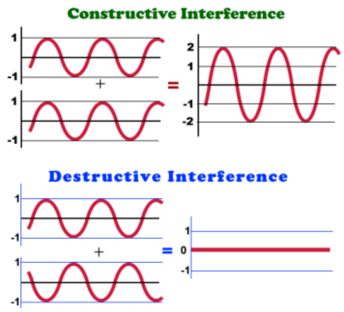

∠-dependence

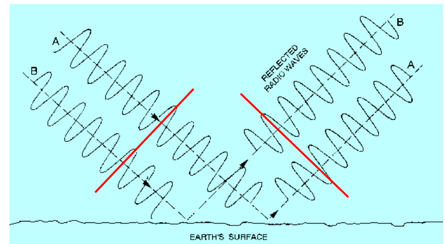
**Absorption is a straightforward concept.**



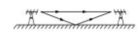


**Phase shifts are responsible for constructive or destructive interference of waves**

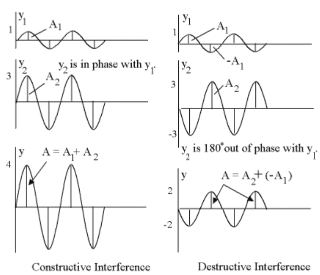


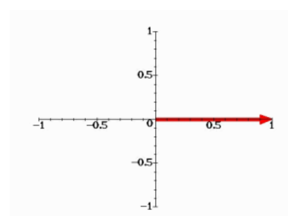

**Notice phase change**



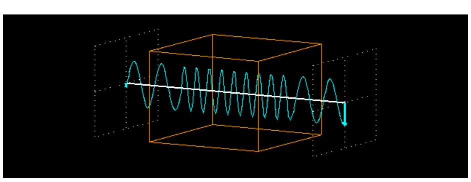
**Phase shifts are responsible for constructive or destructive interference of waves**

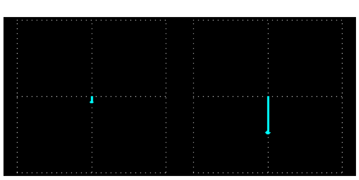



**Polarization changes occur on refraction, reflection (HF) and scattering (VHF).**

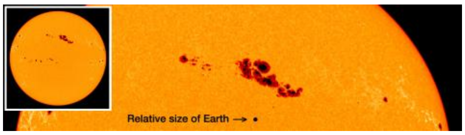


**Random changes in polarization are known as Faraday rotation**

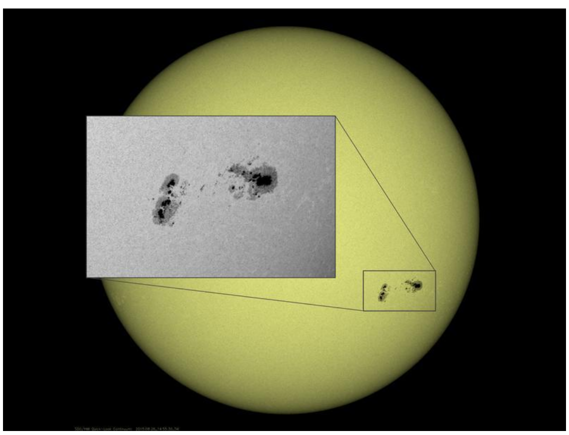


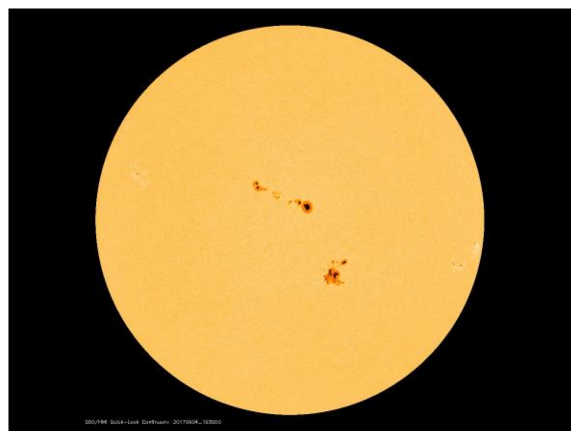


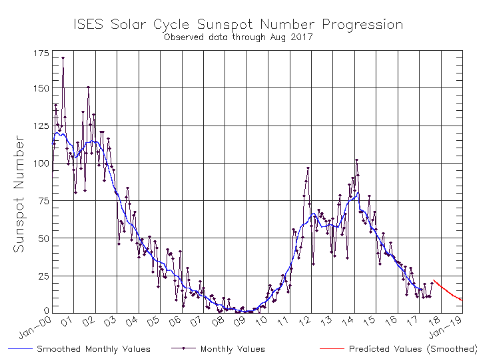
**Solar activity is responsible for the degree of ionization of the ionosphere, especially sunspots which produce a lot of UV radiation**

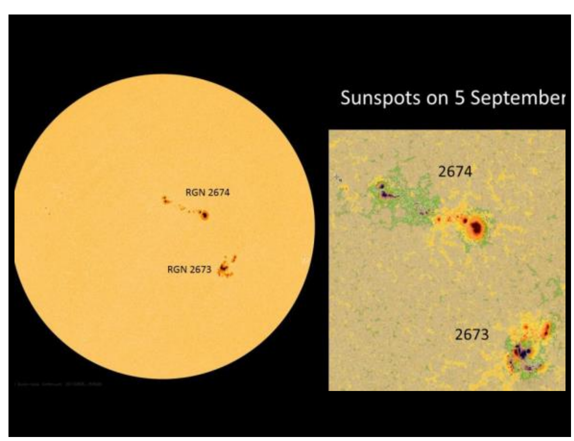



**Cycle is ~11 years**

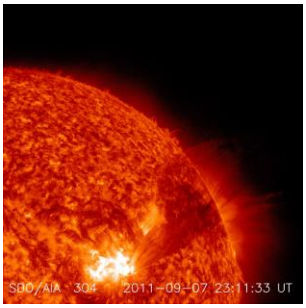




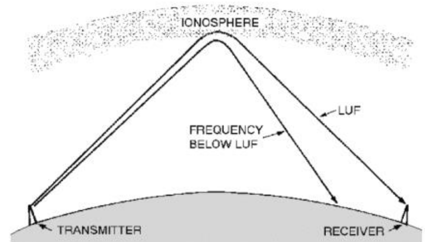


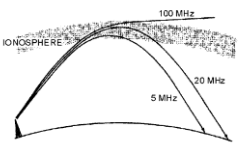
**Solar flares (coronal mass ejections) produce EM and particles which can disrupt radio communications**




**There is also a lowest usable frequency (LUF)**




**Predicting propagation on MF and HF**



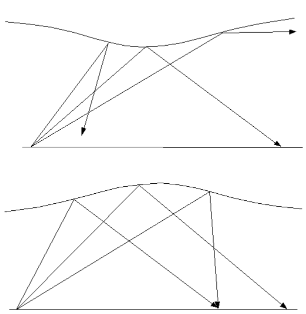

**Critical $f_c$ is that above which no refraction back to earth occurs**

NVI

**The maximum usable frequency (MUF) is closely related to the critical frequency** $MUF = f_c (\csc\theta)$

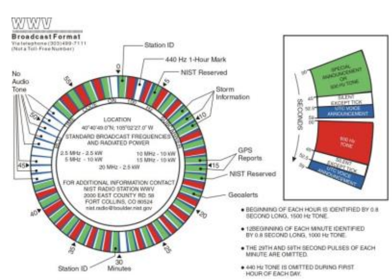
**The optimum working frequency is ~85% of the MUF**

**Many beacon and time stations can be used to predict propagation conditions**



**Ionospheric undulation**

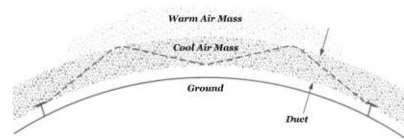
**WWV (Fort Collins, Co):2.5, 5, 10, 15, 20 MHz +18min♂; WWVH (Hawaii): 2.5, 5, 10, 15 MHz +45 min♀**



**CHU (Ottawa) 3.33, 7.850, 14.67 MHz**

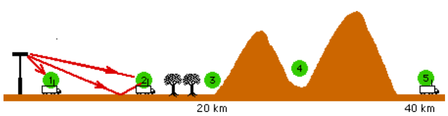
**NCDXF beacons (page 6.20 and Fig 6.10)**


**Ducting for some distance is possible**




**VHF and UHF propagation**

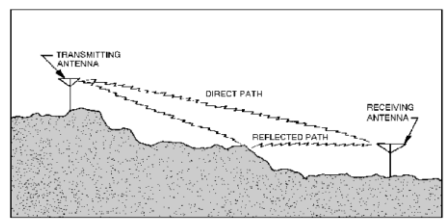
**Line-of-sight propagation, refraction at ionosphere not involved**



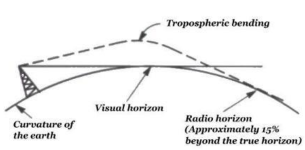

**However, refraction by ° T, reflection, diffraction and scattering occur**

**Some special modes of propagation exist**

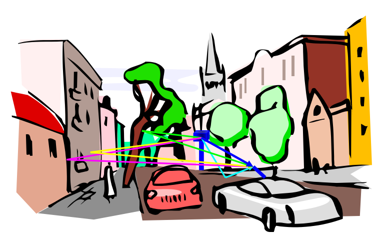
**Reflection contributes to multi-path propagation and fading**



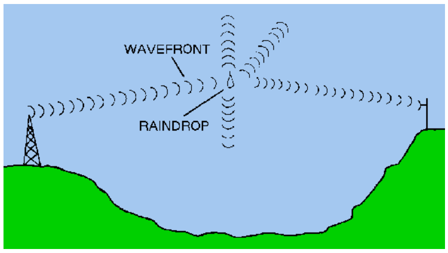

**Some tropospheric bending occurs on VHF and UHF**




**Temperature differences at various altitudes affect signal path**

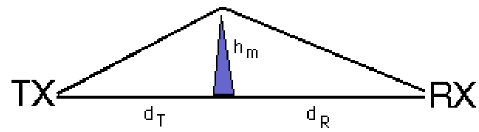


**Reflection from buildings also causes multi-path propagation**



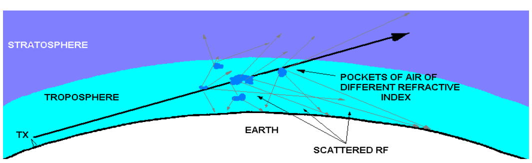

At VHF and UHF frequencies scattering by raindrops is important. Also absorption by leaves

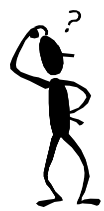
**Diffraction (Quantum effect)**

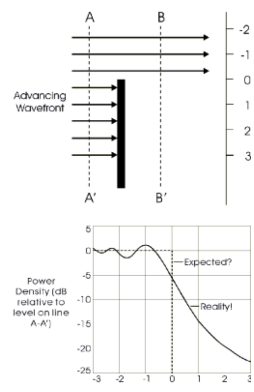




**Tropospheric scatter (troposcatter) can occur.**

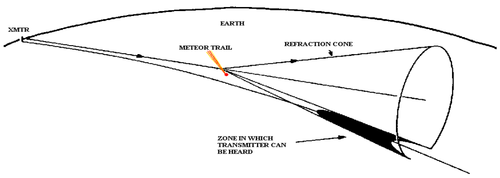





**Special modes on VHF and UHF**

**Sporadic E, Auroral, Meteor scatter, Sleet scatter, Lightning, Aircraft, Trans-equatorial, EME….**




**Review the properties of MF and HF bands on pages 6.12 – 6.14 and VHF and UHF bands on pages 6.17 – 6.18.**

## How about a few questions from the IC question bank?

## Sample Questions From The IC Question Bank

**A. The medium which reflects HF radio waves back to the earth's surface is called:**
1) biosphere
2) stratosphere
3) ionosphere
4) troposphere

**B. All communications frequency throughout the spectrum are affected in varying degrees by:**
1) atmospheric conditions
2) ionosphere
3) aurora borealis
4) sun

**C. Solar cycles have an average length of:**
1) 1 year
2) 3 years
3) 6 years
4) 11 years

**D. Wave energy produced on frequencies below 4 MHz during daylight hours is almost always absorbed by the - layer:**
1) C
2) D
3) E
4) F

**E. If the distance to Europe from your location is approximately 5000 km what sort of propagation is the most likely to be involved?**
1) sporadic-E
2) tropospheric scatter
3) back scatter
4) Multihop

## Morse Code is dead?

Airports/Heliports (Pilots)
Navigational beacons
Hospitals etc
Gets through when SSB fails
Repeater ID
Beacons
Simpler equipment
Lower bandwidth
SOS
Language/Q codes
Military (Aldis lamp)
Secrecy (High speed burst, Jeremiah Denton Jr.)
Mars Rover (Curiosity) tread pattern

# Thanks for listening and Good luck on the exam!

CW