Alternating Voltage and Current

Topics to be Covered

- **Alternating Current:** instantaneous and r.m.s. current, voltage and power, average power for various combinations of R, L and C circuits, phasor representation of sinusoidal quantities.

Alternating Voltage/Current

- *Direct current* (DC), which is electricity flowing in one direction only. DC is the kind of electricity made by a battery, with definite positive and negative terminals.

- However, the electricity produced by some generators constantly alternates (switches direction) and is therefore known as *alternating current* (AC).

Alternating Voltage/Current

- There are a number of advantages to AC current, the main advantage of AC is that the voltage can be changed using transformers.

- The voltage can be *"stepped-up"* at power stations to a very high voltage so that electrical energy can be transmitted along power lines at low current and therefore experience *low energy loss*.

- The voltage can then be *"stepped-down"* for use in buildings and street lights.

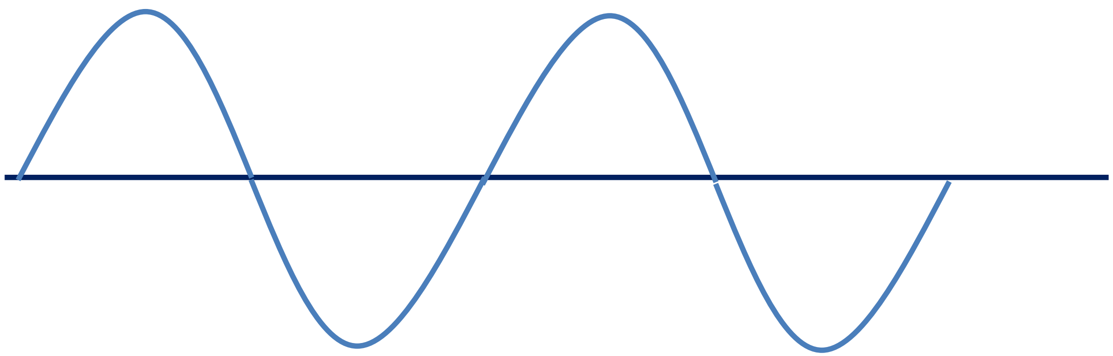
Alternating Voltage/Current Advantages

A list of the advantages of alternating current:

- Easy to be transformed (step up or step down using a transformer).
- Easier to convert from AC to DC than from DC to AC.
- Easier to generate.
- It can be transmitted at high voltage and low current over long distances with less energy lost.
- High frequency used in AC makes it suitable for motors.

Alternating Voltage and Current Generator

- **Output of an *ac* voltage generator**

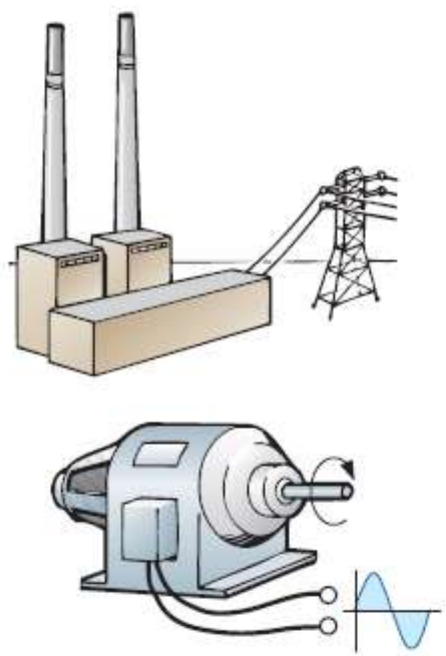


Alternating Voltage and Current Generator

- ***ac* Voltage Generator**
  - The most common source is the typical home outlet, which provides an ac voltage that originates at a power plant.
    - Most power plants are fueled by water power, oil, gas, or nuclear fusion.

Alternating Voltage and Current Generator

- An ac generator (also called an *alternator), is the primary component* in the energy-conversion process.



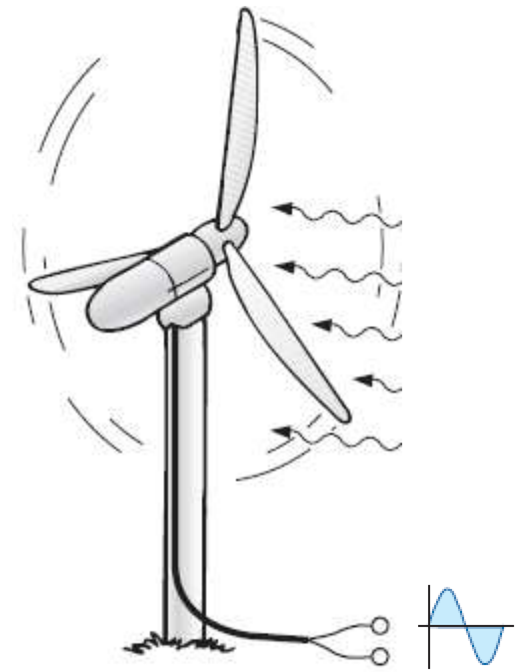
Alternating Voltage and Current Generator

- **For isolated locations where power lines have not been installed, *portable ac generators* are available that run on gasoline.**

- **In the larger power plants, however, an *ac generator* is an integral part of the design.**

Alternating Voltage and Current Generator

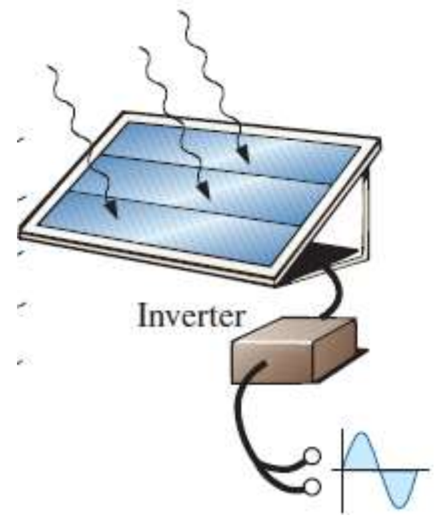
- To conserve our natural resources and reduce pollution, wind power, solar energy, and fuel cells are receiving increasing interest
- The turning propellers of the wind-power station are connected directly to the shaft of an ac generator to provide the ac voltage described above.



Alternating Voltage and Current Generator

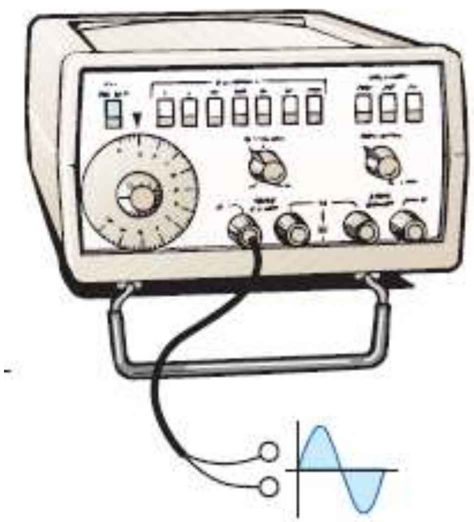
- **Through light energy absorbed in the form of *photons, solar cells* can generate dc voltages.**

- **Through an electronic package called an *inverter, the dc voltage can be converted to one of a sinusoidal* nature.**
  - Boats, recreational vehicles (RVs), and so on, make frequent use of the inversion process in isolated areas.



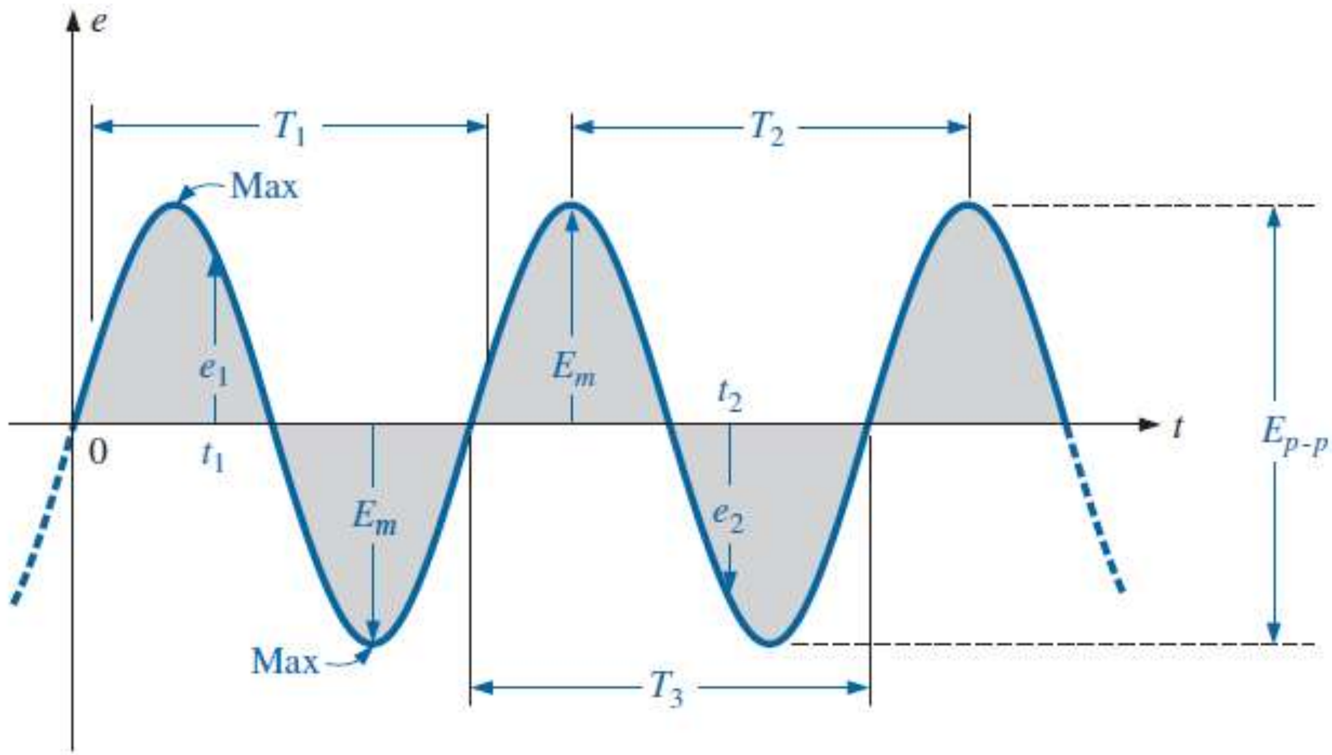
Alternating Voltage and Current Generator

- Sinusoidal ac voltages with characteristics that can be controlled by the user are available from function generators

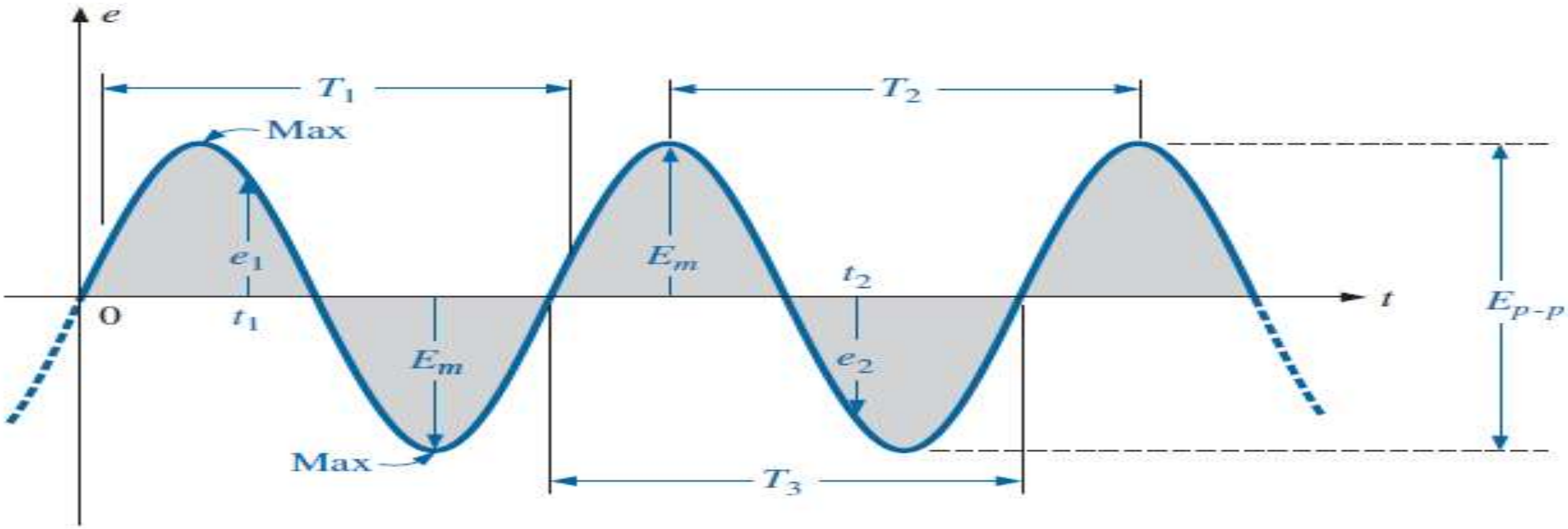


Definitions of Different Terms

- **Parameters of alternating waveform.**



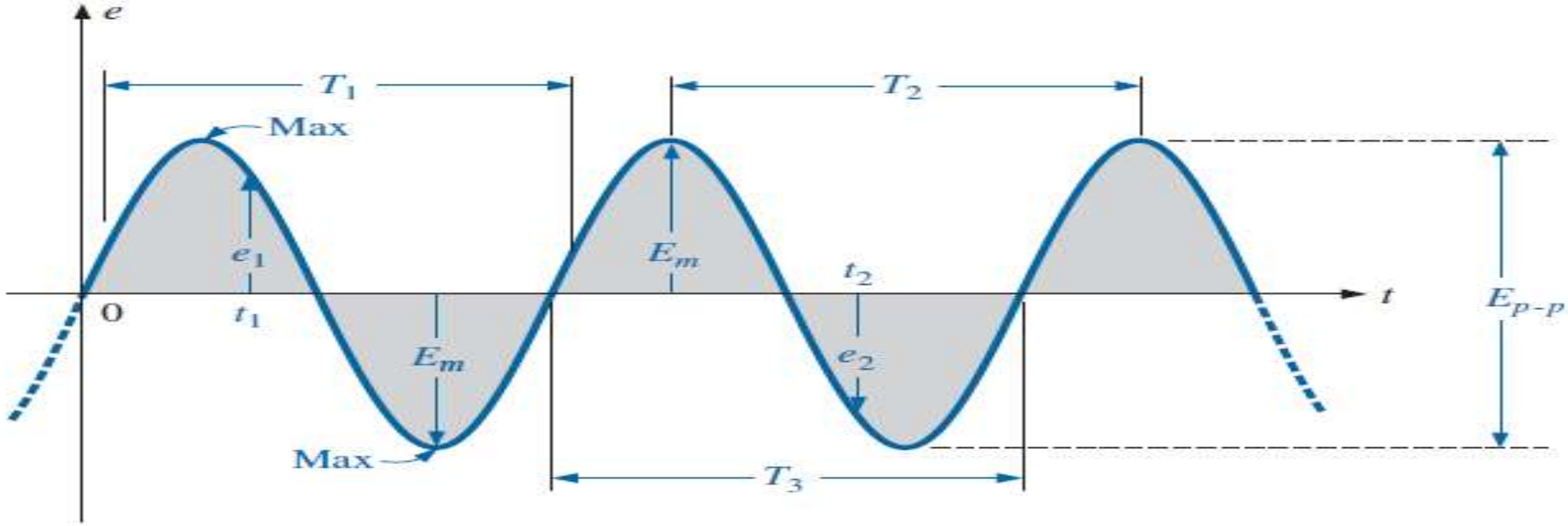
Definitions of Different Terms



- *Waveform:* **The path traced by a quantity, such as the voltage in Fig., plotted as a function of some variable such as time (as above), position, degrees, radians, temperature, and so on.**

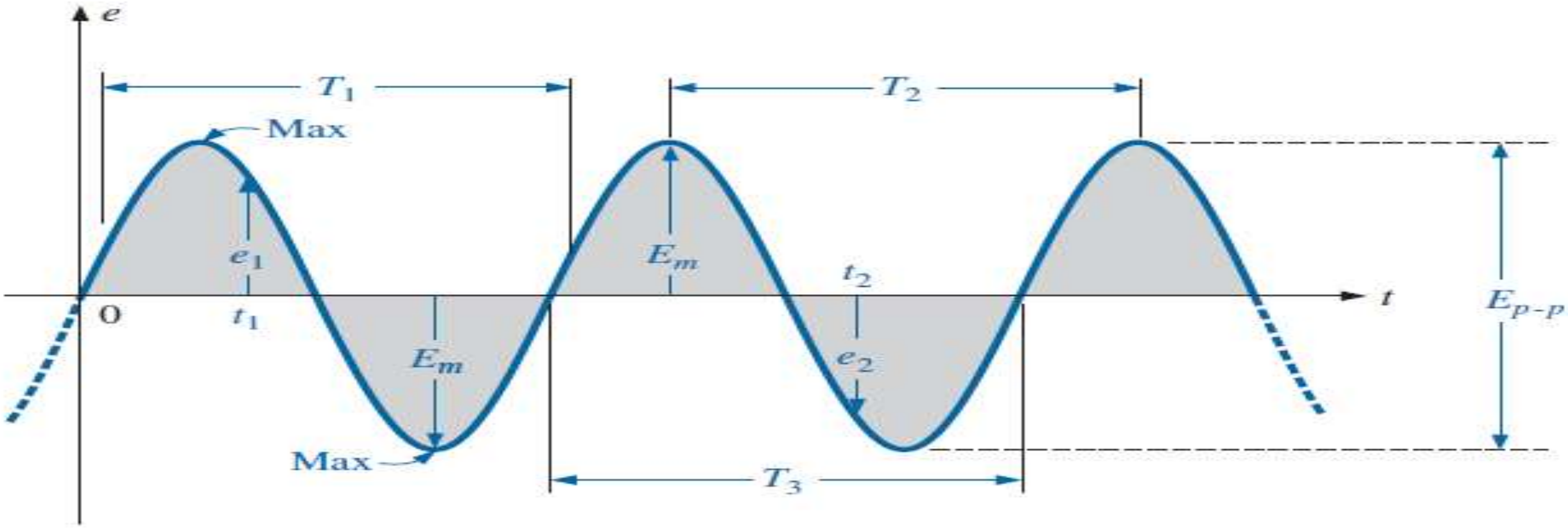
- *Instantaneous Value:* **The magnitude of a waveform** ***at any instant of time*****; denoted by lowercase letters (*e_1, e_2 in Fig.*).**

Definitions of Different Terms



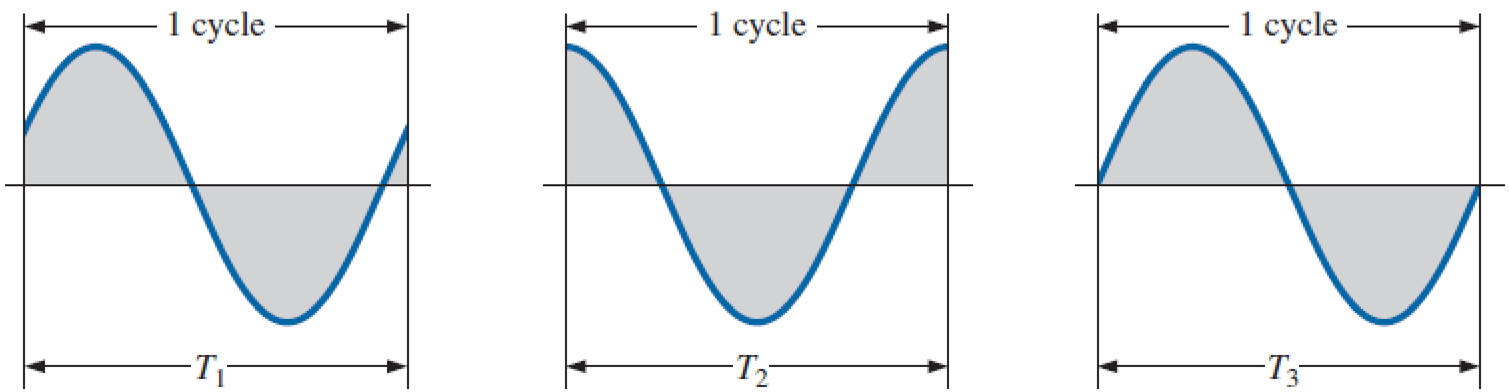
- ***Peak Amplitude:*** The maximum value of a waveform as measured from its *average, or mean value, denoted by uppercase letters [such* as *E_m(Fig.) for sources of voltage and V_m for the voltage drop* across a load].
  - For the waveform in Fig., the average value is zero volts, and ***E_m****is as defined by the figure.*
- ***Peak Value:*** The maximum instantaneous value of a function as measured from the zero volt level. For the waveform in Fig., the peak amplitude and peak value are the same, since the average value of the function is zero volts.

Definitions of Different Terms



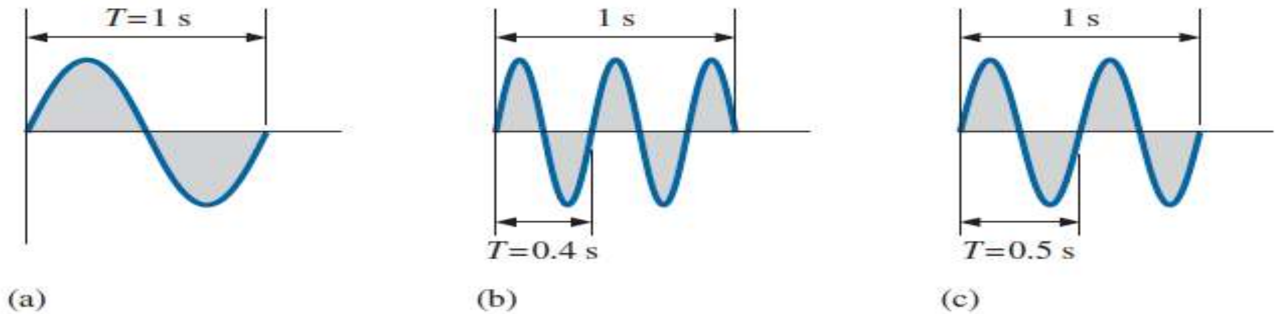
- ***Peak-to-Peak Value:*** Denoted by $E_{p\text{-}p}$, *or* $V_{p\text{-}p}$ *(as shown in Fig.),* the full voltage between positive and negative peaks of the waveform, that is, the sum of the magnitude of the positive and negative peaks.
- ***Periodic Waveform:*** A waveform that continually repeats itself after the same time interval. The waveform in Fig. is a periodic waveform.

Definitions of Different Terms



- ***Period (T):*** *The time taken to complete one period of a periodic waveform.*
- ***Cycle:*** The portion of a waveform contained in one period of time. The cycles within T_1, T_2, *and* T_3 in Fig. may appear different in Fig., but they are all bounded by one period of time and therefore satisfy the definition of a cycle.

Definitions of Different Terms



- ***Frequency (f):*** *The number of cycles that occur in 1 s. The frequency* of the waveform in Fig. (a) is 1 cycle per second, and for Fig. (b), 2.5 cycles per second. If a waveform of similar shape had a period of 0.5 s [Fig. (c)], the frequency would be 2 cycles per second.
- The unit of measure for frequency is the *hertz (Hz).*

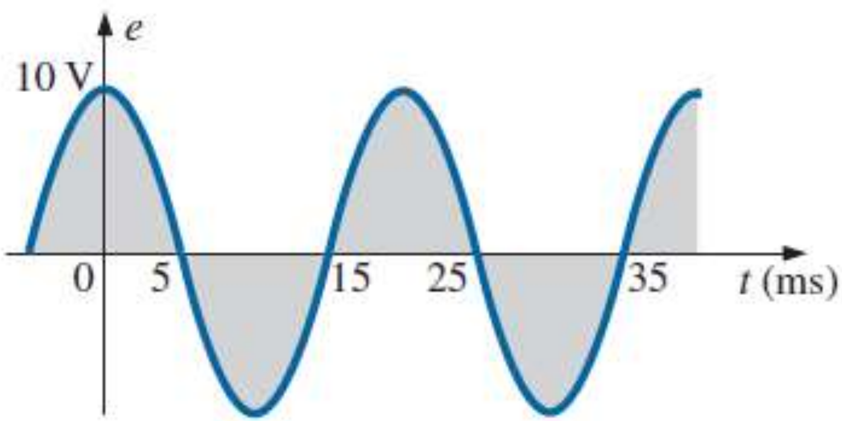
$$\boxed{1 \text{ hertz (Hz)} = 1 \text{ cycle per second (cps)}}$$

Since the frequency is inversely related to the period—that is, as one increases, the other decreases by an equal amount—the two can be related by the following equation:

$$\boxed{f = \frac{1}{T}} \qquad \boxed{T = \frac{1}{f}}$$

Definitions of Different Terms

- **Determine the frequency of the waveform in Fig.**

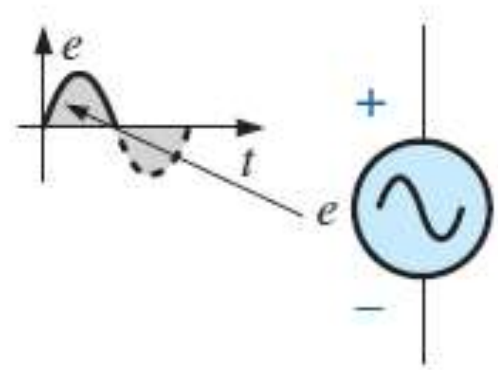


From the figure, $T = (25\text{ ms} - 5\text{ ms})$ or $(35\text{ ms} - 15\text{ ms}) = 20\text{ ms}$, and

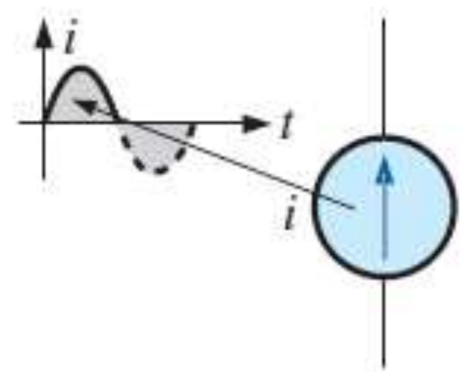
$$f = \frac{1}{T} = \frac{1}{20 \times 10^{-3}\text{ s}} = \mathbf{50\ Hz}$$

Polarities of Alternating Voltage and Current

- **A positive sign is applied if the voltage is above the axis, as shown in Fig. (a).**
- **For a current source, the direction in the symbol corresponds with the positive region of the waveform, as shown in Fig. (b).**
- **For any quantity that will not change with time, an uppercase letter such as *V or I is used.***
- ***For expressions that are time dependent or that represent* a particular instant of time, a lowercase letter such as *e or i is used.***



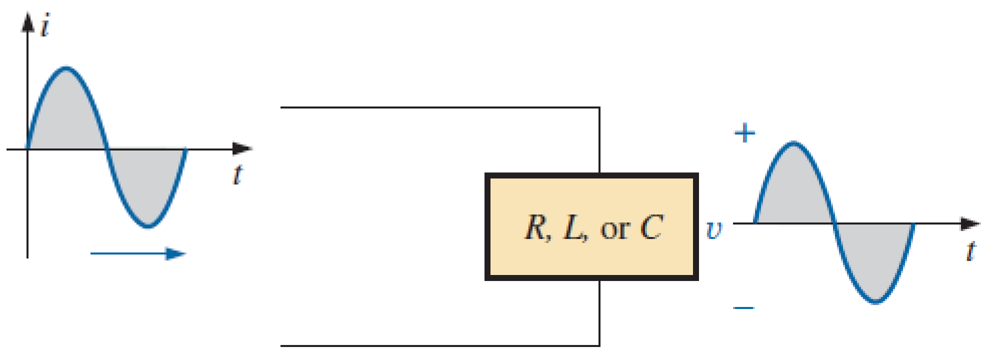
(a)



(b)

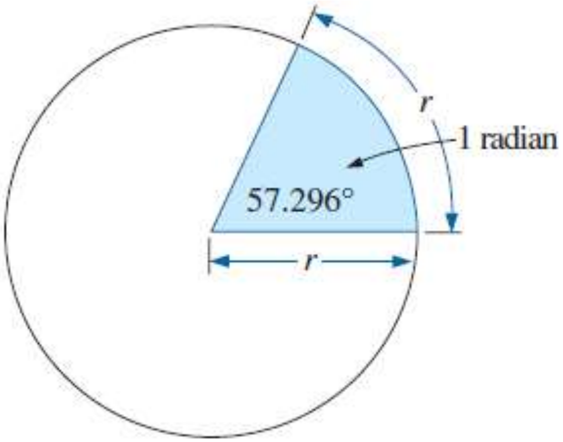
The Sinusoidal Waveform

- ***The sinusoidal waveform is the only alternating waveform whose shape is unaffected by the response characteristics of R, L, and C elements.***
- **In other words, if the voltage across (or current through) a resistor, inductor, or capacitor is sinusoidal in nature, the resulting current (or voltage, respectively) for each will also have sinusoidal characteristics, as shown in Fig.**



The Sinusoidal Waveform

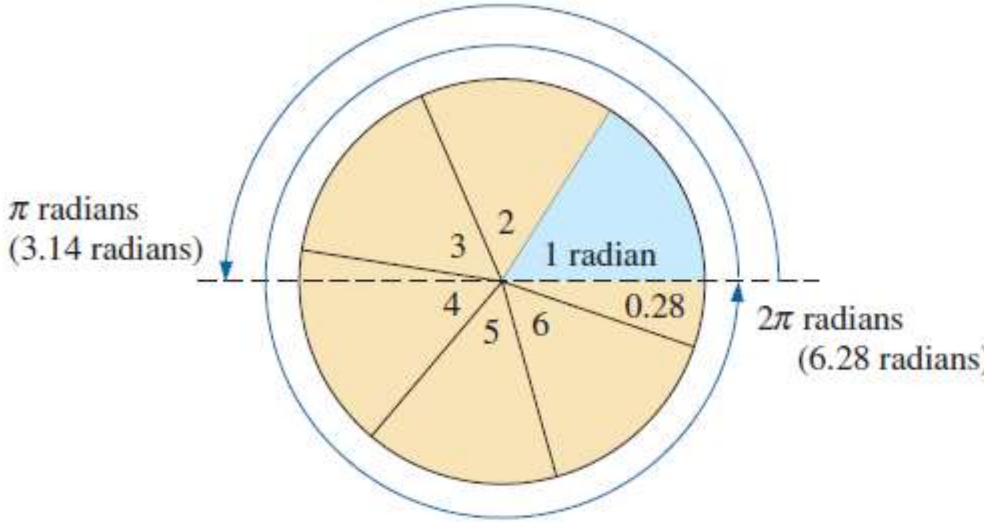
- The unit of measurement for the horizontal axis can be time (as appearing in the figures thus far), **degrees, *or radians***.
- *The term **radian** can* be defined as follows: *If we mark off a portion of the circumference of a circle by a length equal to the radius of the circle*, as shown in Fig., *the angle resulting is called 1 radian.*



$$\boxed{1 \text{ rad} = 57.296° \cong 57.3°}$$

The Sinusoidal Waveform

$$\boxed{2\pi \text{ rad} = 360^\circ}$$



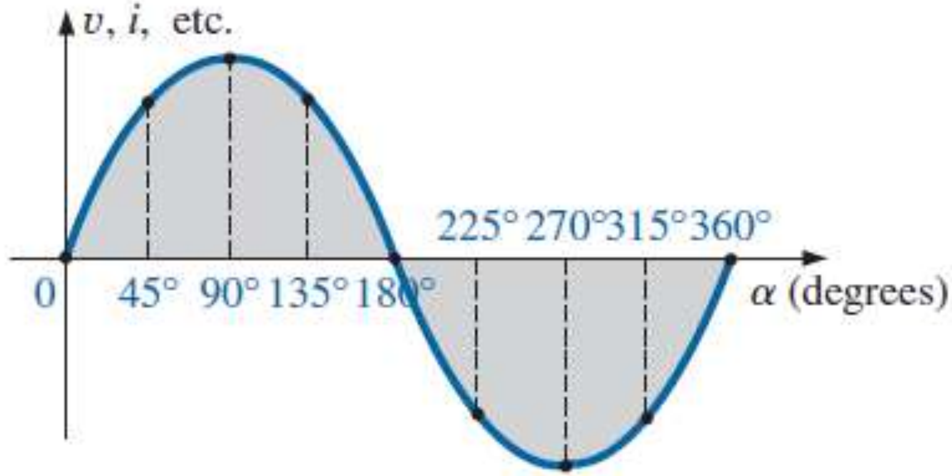
$$\boxed{\text{Radians} = \left(\frac{\pi}{180^\circ}\right) \times (\text{degrees})}$$

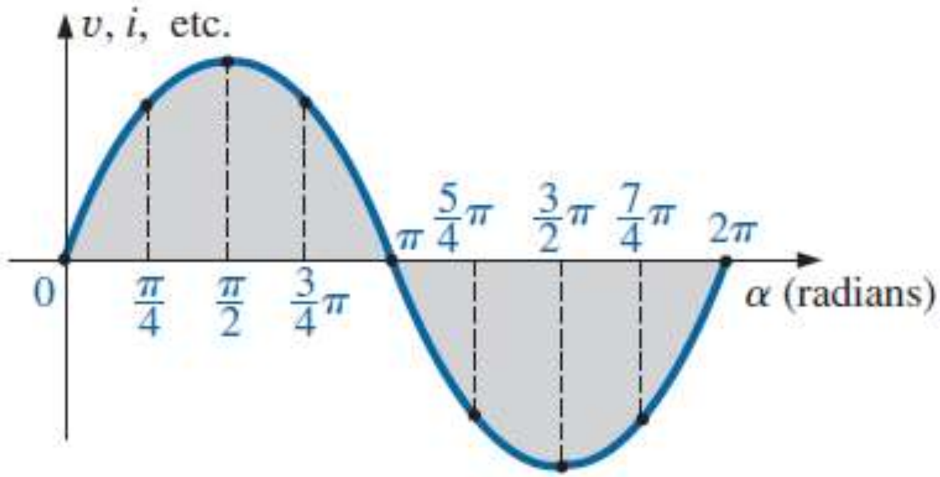
$$\mathbf{90^\circ}\text{:}\quad \text{Radians} = \frac{\pi}{180^\circ}(90^\circ) = \frac{\pi}{\mathbf{2}}\ \textbf{rad}$$

$$\boxed{\text{Degrees} = \left(\frac{180^\circ}{\pi}\right) \times (\text{radians})}$$

$$\frac{\pi}{\mathbf{3}}\ \textbf{rad}\text{:}\quad \text{Degrees} = \frac{180^\circ}{\pi}\left(\frac{\pi}{3}\right) = \mathbf{60^\circ}$$

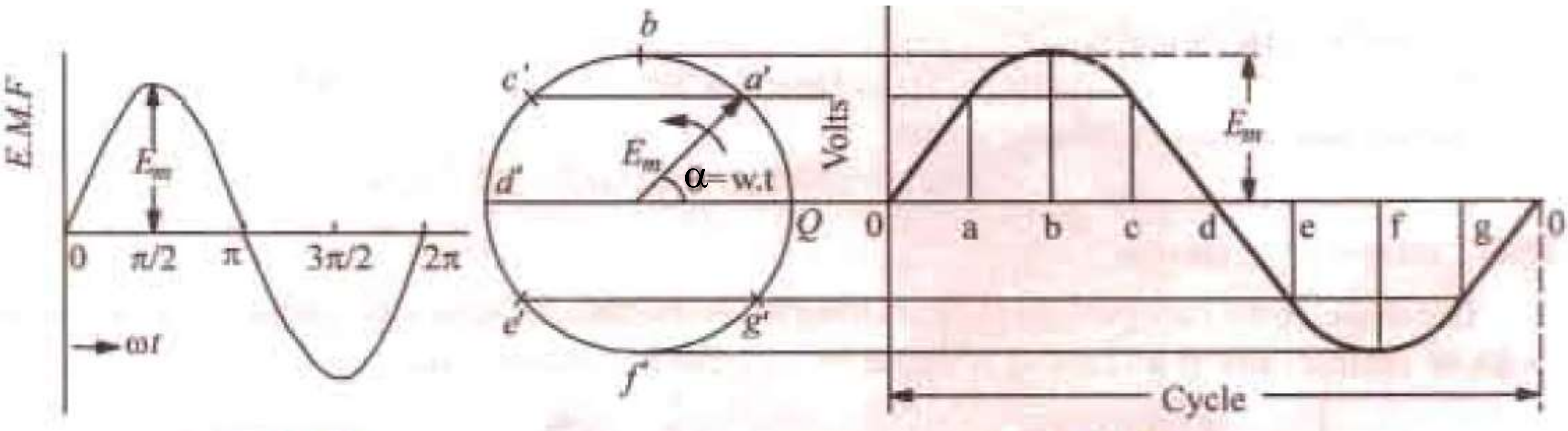
The Sinusoidal Waveform





The Sinusoidal Waveform

The sinusoidal waveform can be derived from the length of the vertical projection of a radius vector rotating in a uniform circular motion about a fixed point.



The velocity with which the radius vector rotates about the center, called the *angular velocity*, can be determined from the following equation:

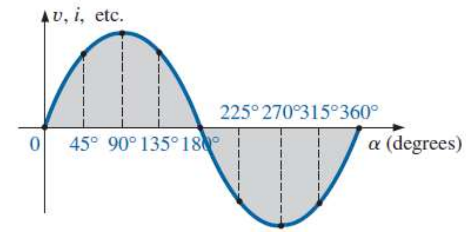
$$\boxed{\text{Angular velocity} = \frac{\text{distance (degrees or radians)}}{\text{time (seconds)}}}$$

$$\boxed{\omega = \frac{\alpha}{t}}$$

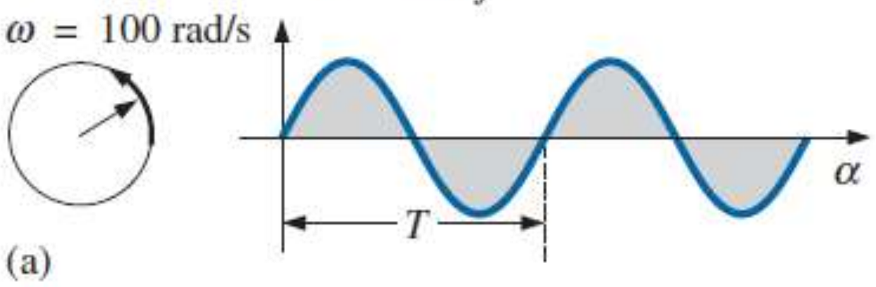
$$\boxed{\alpha = \omega t}$$

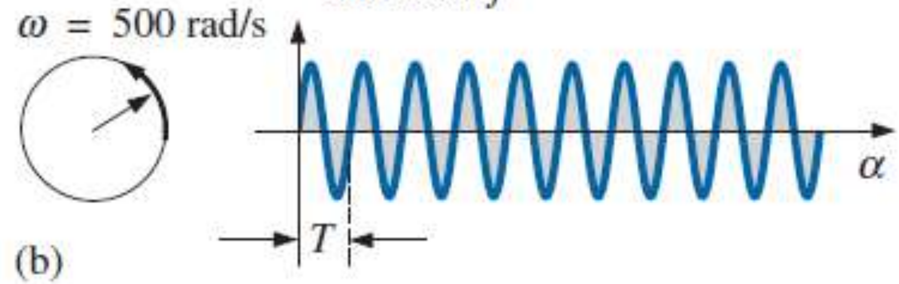
The Sinusoidal Waveform

The time required to complete one revolution is equal to the period (T) of the sinusoidal waveform in Fig. The radians subtended in this time interval are 2π. Substituting, we have:



$$\boxed{\omega = \frac{2\pi}{T}} \quad \text{(rad/s)} \qquad \boxed{\omega = 2\pi f} \quad \text{(rad/s)} \qquad f = 1/T.$$





The Sinusoidal Waveform

P-1: Determine the angular velocity of a sine wave having a frequency of 60 Hz.

$$\omega = 2\pi f = (2\pi)(60 \text{ Hz}) \cong \mathbf{377\ rad/s}$$

P-2: Given ***ω = 200 rad/s***, determine how long it will take the sinusoidal waveform to pass through an angle of 90°.

$$\alpha = \omega t, \text{ and}$$

$$t = \frac{\alpha}{\omega}$$

Thus,

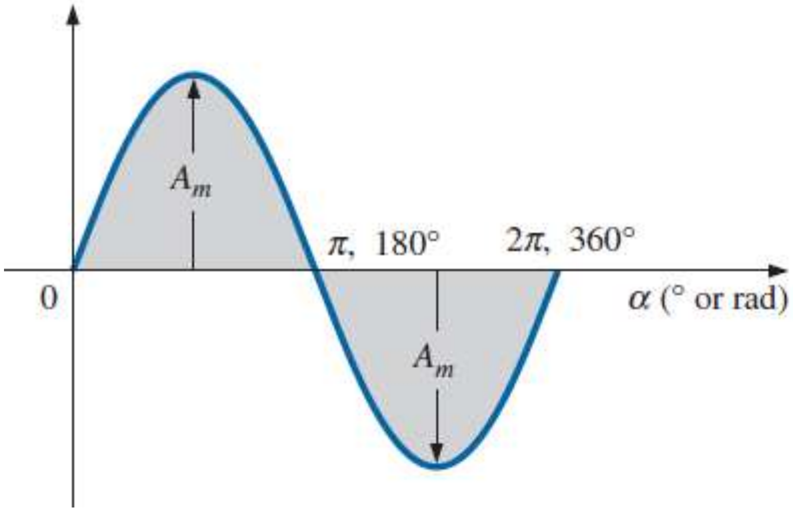
$$t = \frac{\alpha}{\omega} = \frac{\pi/2 \text{ rad}}{200 \text{ rad/s}} = \frac{\pi}{400} \text{ s} = \mathbf{7.85\ ms}$$

General Format for Sinusoidal Voltage or Current

- **The basic mathematical format for the sinusoidal waveform is**

$$\boxed{A_m \sin \alpha}$$

$$\boxed{A_m \sin \omega t}$$



For a particular angular velocity, the longer the time, the greater the number of cycles shown.

For a fixed time interval, the greater the angular velocity, the greater the number cycles generated.

General Format for Sinusoidal Voltage or Current

- **For electrical quantities such as current and voltage, the general format is**

$$i = I_m \sin \omega t = I_m \sin \alpha$$

$$e = E_m \sin \omega t = E_m \sin \alpha$$

where the capital letters with the subscript m represent the amplitude, and the lowercase letters.

i and e represent the instantaneous value of current and voltage, respectively, at any time t.

General Format for Sinusoidal Voltage or Current

P-1: Given *$e = 5 \sin\alpha$, determine e at $\alpha = 40°$ and $\alpha = 0.8\pi$.*

For $\alpha = 40°$,

$$e = 5 \sin 40° = 5(0.6428) = \mathbf{3.21\ V}$$

For $\alpha = 0.8\pi$,

$$\alpha\,(°) = \frac{180°}{\pi}(0.8\pi) = 144°$$

$$e = 5 \sin 144° = 5(0.5878) = \mathbf{2.94\ V}$$

General Format for Sinusoidal Voltage or Current

The angle at which a particular voltage level is attained can be determined by rearranging the equation $e = E_m \sin \alpha$ ***as:***

$$\sin \alpha = \frac{e}{E_m}$$

$$\boxed{\alpha = \sin^{-1} \frac{e}{E_m}}$$

Similarly, for a particular current level,

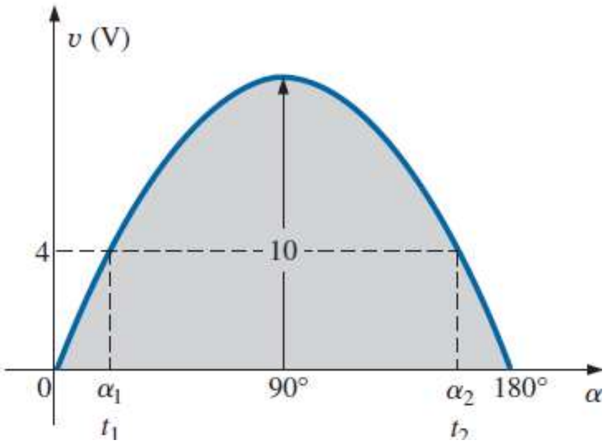
$$\boxed{\alpha = \sin^{-1} \frac{i}{I_m}}$$

General Format for Sinusoidal Voltage or Current

Problem: a. Determine the angle at which the magnitude of the sinusoidal function *y = 10 sin 377t* is *4 V.*

b. Determine the time at which the magnitude is attained.

$$\alpha_1 = \sin^{-1}\frac{v}{E_m} = \sin^{-1}\frac{4\text{ V}}{10\text{ V}} = \sin^{-1}0.4 = \mathbf{23.58^\circ}$$



However, Fig. reveals that the magnitude of ***4 V*** (positive) will be attained at two points between **0°** and **180°**. The second intersection is determined by

$$\alpha_2 = 180^\circ - 23.578^\circ = \mathbf{156.42^\circ}$$

b. $\alpha = \omega t$, *and so* $t = \alpha / \omega$*. However,* α *must be in radians.* Thus,

$$\alpha\,(\text{rad}) = \frac{\pi}{180^\circ}(23.578^\circ) = 0.412\text{ rad}$$

$$t_1 = \frac{\alpha}{\omega} = \frac{0.412\text{ rad}}{377\text{ rad/s}} = \mathbf{1.09\text{ ms}}$$

$$\alpha\,(\text{rad}) = \frac{\pi}{180^\circ}(156.422^\circ) = 2.73\text{ rad}$$

$$t_2 = \frac{\alpha}{\omega} = \frac{2.73\text{ rad}}{377\text{ rad/s}} = \mathbf{7.24\text{ ms}}$$

HOME WORK

P-1: Determine the frequency and period of the sine wave with angular velocity of 500 rad/s.

P-2: Find the angle through which a sinusoidal waveform of 60 Hz will pass in a period of 5 ms.

Reference: *PPTX Collected* , ***Prof. Dr. Dipankar Das***