TYPES OF CURRENT AND WAVEFORMS

- Waveform is the geometric configuration of a current, which is described based on its phase, symmetry, electrical balance, and shape.
- The characteristics of electrical currents can be described as parameters.
- The Clinical Electrophysiology Section of the American Physical Therapy Association (APTA) in 1986 published a guide to electrical stimulation terminology that included recommended standard terminology and definitions; a second edition was published in 2000.
- Electrical current waveforms can be considered to be of three types: direct current (DC), alternating current (AC), and pulsed current (PC).
- All currents have parameters in the vertical (y coordinate) and horizontal (x coordinate) directions. Parameters in the horizontal axis are used to describe and quantify time or duration characteristics of current in (milli- or microseconds), whereas parameters in the vertical axis are used to describe or quantify magnitude or intensity (in milli- or microamps or milli- or microvolts).
- By convention, deviation from the isoelectric baseline in the upward direction implies current flow in the positive direction; conversely, deviation in the downward direction implies flow in the negative direction.

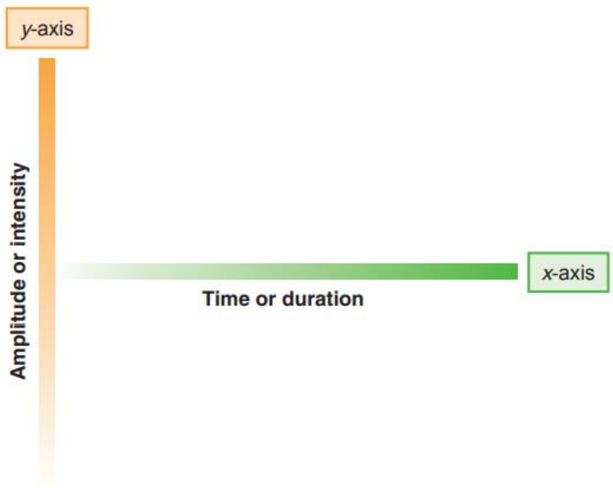


Fig 9 ■ 8 Basic *x*-*y* axes for time and amplitude. Time may be in seconds (sec), milliseconds (msec, 10^{-3}), or microseconds (μsec, 10^{-6}). Intensity may be in volts (V), millivolts (10^{-3}, mV), microvolts (10^{-6}, μV), amperes (amp), milliamperes (10^{-3}, mA), or microamperes (10^{-6}, μA).

DIRECT CURRENT

- Direct current is the continuous unidirectional flow of electrons for atleast 1 second.
- Variations of DC exist, but to accurately be called DC, they must remain unidirectional and uninterrupted for a period of time. Other forms of DC include interrupted DC, where the direction of flow ceases after 1 second before resuming in the same direction for at least 1 second; reversed DC, where the flow ceases after 1 second before resuming in the opposite direction for at least 1 second; and interrupted reversed DC, which is a combination of both.
- The most common clinical uses of DC are for iontophoresis and wound care.

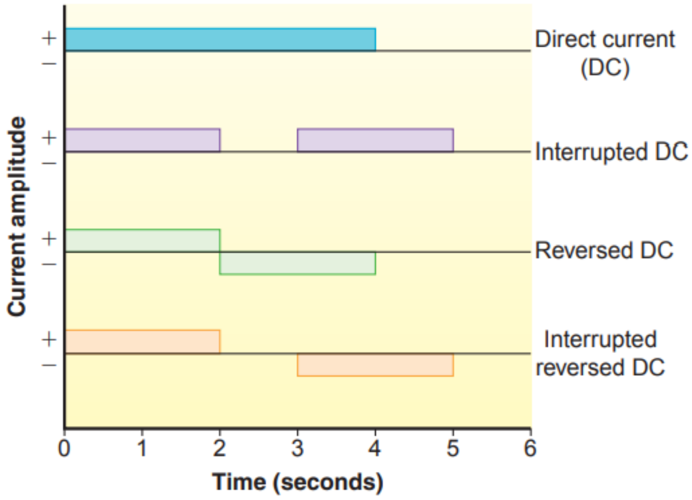


Fig 9 ■ 9 Direct current (DC) comes in many forms, conventional DC (top) being the most commonly used.

ALTERNATING CURRENT

- In contrast to DC, alternating current (AC) is the uninterrupted bidirectional flow of ions or electrons and must change direction at least one time per second. The rate at which AC switches direction is termed frequency and is described with the international unit hertz (Hz) or in the unit cycles per second.
- Clinical use of pure sinusoidal AC is not common; however, modulated forms of AC, such as burst-modulated AC (i.e., Russian current) and amplitude-modulated AC (i.e., interferential current), are commonly used.

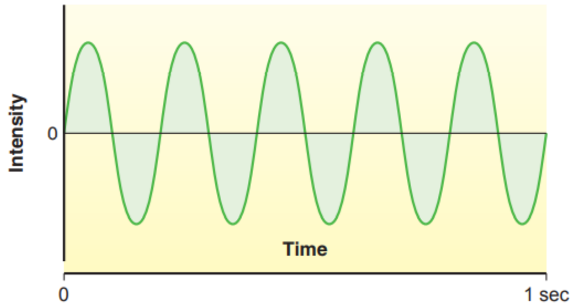


Fig 9 ▪ 11 Alternating current (AC) as a sinusoidal waveform.

PULSED CURRENT

- Because the electrophysiological effects of DC or AC are not well suited for most electrotherapeutic applications, a third category of current has been designated: pulsed current (PC). Pulsed current, sometimes termed pulsatile current, is the uni- or bidirectional flow of ions or electrons that periodically ceases for a period of time before the next electrical event.
- Pulsed current is an interrupted flow of charged particles where the current flows in a series of pulses separated by periods where no current flows. The current may flow in only one direction during a pulse, which is known as a monophasic pulsed current, or it may flow back and forth during a pulse, which is known as a biphasic pulsed current.
- Monophasic pulsed currents may be used for any clinical application of electrical stimulation but are most commonly used to promote tissue healing and for acute edema management. The most commonly encountered monophasic pulsed current is high-volt pulsed current (HVPC), also known as pulsed galvanic current.

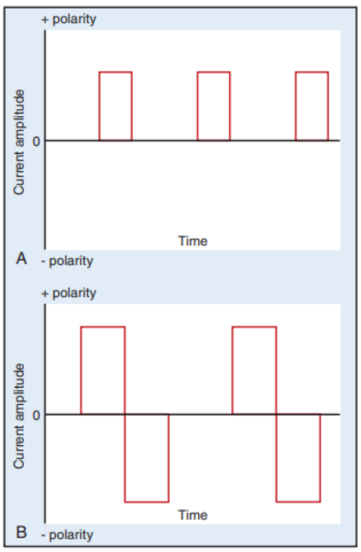


FIG 11-6 **A**, Monophasic; and **B**, biphasic pulsed currents.

- Common forms of pulsed current include square, rectangular, and triangular pulses.

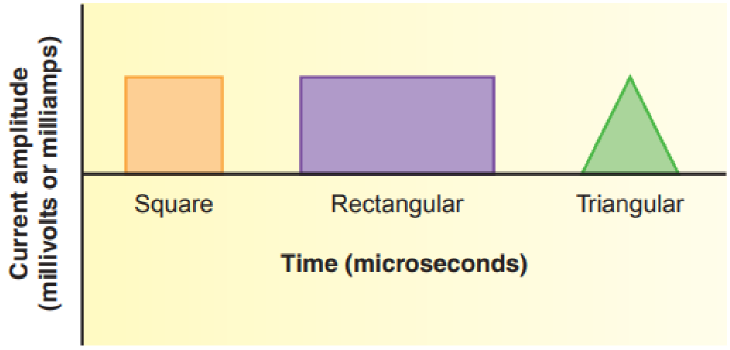
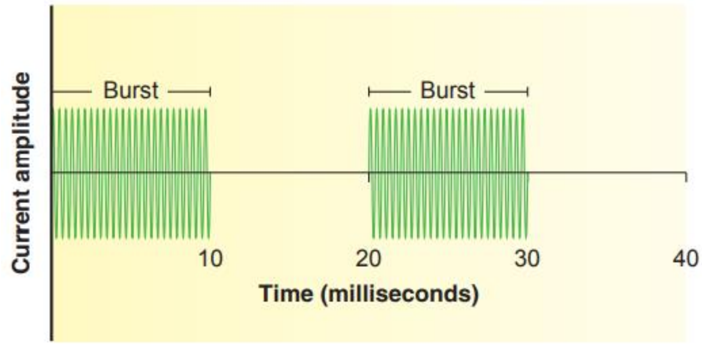


Fig 9 ▪ 12 Pulsed current comes in many shapes, including square, rectangular, and triangular waveforms.

- The generation of two or more consecutive pulses separated from the next series of consecutive pulses is termed a burst, and the time between bursts is the interburst interval.



PC is used for stimulating skeletal muscle for strengthening and activity. Because PC is a series of pulses, muscle fibers can be stimulated frequently, resulting in tetanic contraction. But what will happen if using DC? Won't this result in a tetanic contraction because DC flows continuously? No! DC will depolarize the muscle and cause a single twitch, but only one. To get a tetanic contraction, the muscle must depolarize and repolarize before depolarizing again. The time between successive pulses of pulsed current allows the muscle fibers to repolarize so they can be depolarized again. DC results in a sustained state of depolarization. The muscle cannot repolarize until the DC temporarily ceases.

- Pulsed current may be monophasic or biphasic, with a phase being the flow of current in one direction for a short period of time. A monophasic pulse deviates from the isoelectric line in only one direction, depending on what direction the current initially flows before ceasing (i.e., returning to the isoelectric line).
- Monophasic pulsed current is the delivery of repeated monophasic pulses separated from each other by an interpulse interval; it is produced by intermittently interrupting a DC current source.
- In contrast to a monophasic pulse, a biphasic pulse is one that deviates from the isoelectric line first in one direction, then in the other direction. Biphasic pulsed current, therefore, is the delivery of repeated biphasic pulses separated from the next pulse by an interpulse interval. By definition, with monophasic pulsed current, a pulse and a phase are synonymous.

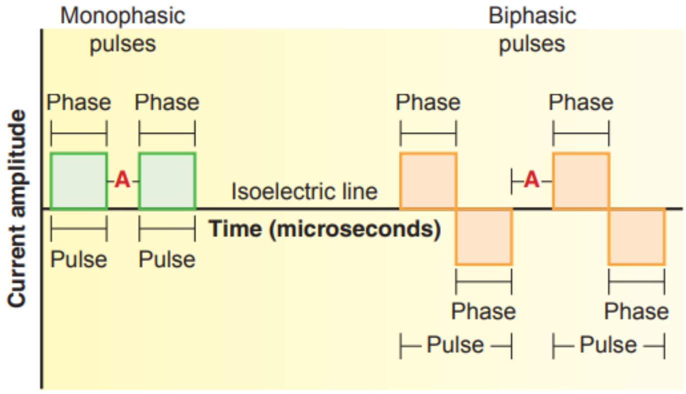


Fig 9 ▪ 14 Mono- and biphasic current. For monophasic pulses, *phase* and *pulse* are synonymous. Biphasic pulses have phases that deviate from the isoelectric line in different directions. (A represents the interpulse interval.)

- A biphasic pulsed current may be symmetrical or asymmetrical, and if asymmetrical, may be balanced or unbalanced. With a symmetrical or a balanced asymmetrical biphasic pulsed current, the charge of the phases are equal in amount and opposite in polarity, resulting in a net charge of zero. With an unbalanced asymmetrical biphasic current, the charge of the phases are not equal, and there is a net charge. In general, the biphasic pulsed current waveforms available are balanced.

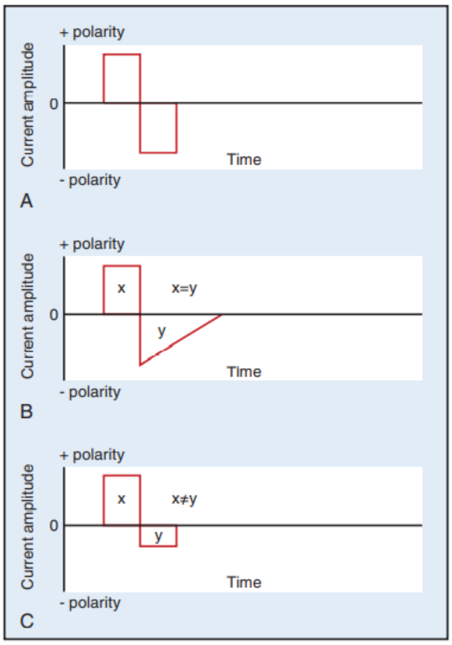


FIG 11-8 **A**, Symmetrical; **B**, balanced asymmetrical; and **C**, unbalanced asymmetrical biphasic pulsed currents.

- The amplitude-dependent characteristics used to describe waveforms reflect the y coordinate when plotting waveforms. Amplitude, often referred to as intensity, is the magnitude of current or voltage with respect to the isoelectric or baseline on the x-y current-time plot.
- Amplitude is reported in units of current (amps, milliamps, or microamps) or voltage (volts, millivolts, or microvolts) and can be described in terms of a single phase or both phases. Most uses of ES use milliampere amplitude. The highest current or voltage reached in a phase of a monophasic pulse or in any one phase of a biphasic waveform is termed the peak amplitude. The highest value measured from the peak of the first phase to the peak of the second phase of a biphasic waveform is termed the peak-to-peak amplitude. For monophasic waves, there is no peak-to-peak value.
- The time-dependent characteristics used to describe waveforms reflect the x coordinate when plotting waveforms. Phase duration is the time from the beginning of one phase to its end. Pulse duration is the time from the beginning to the end of all phases plus the interphase interval within one pulse. The interphase interval (or intrapulse interval) is the time between phases of a single pulse, whereas the interpulse interval is the time between successive pulses. Phase and pulse duration are most commonly reported in milliseconds (msec) or microseconds (sec).

- Pulse duration is the total time elapsed from the beginning to the end of a single pulse, including the inter-phase (intrapulse) interval.
- Pulse duration is often labeled pulse width on many devices. This terminology is not preferred because pulse duration is a unit of time, whereas width implies a unit of linear measure.

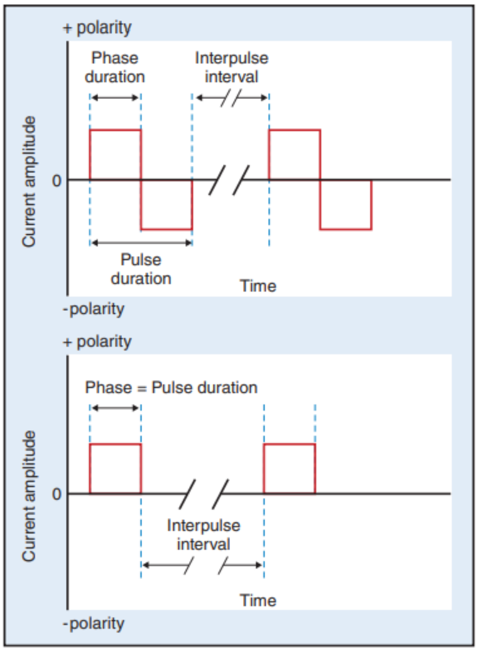


FIG 11-9 Pulse duration, phase duration, and interpulse interval for biphasic and monophasic pulsed currents.

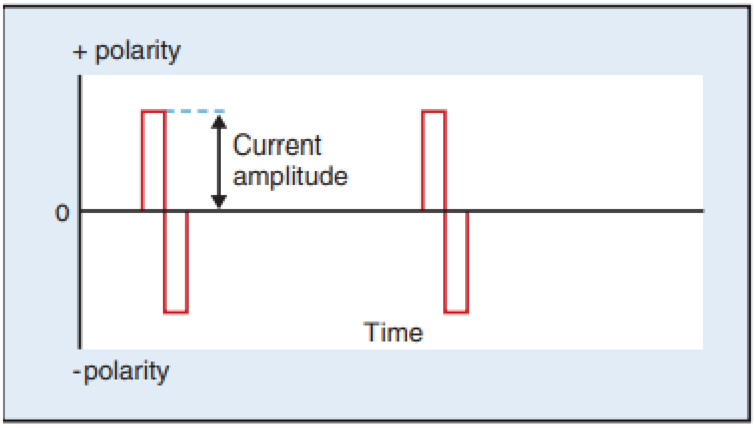
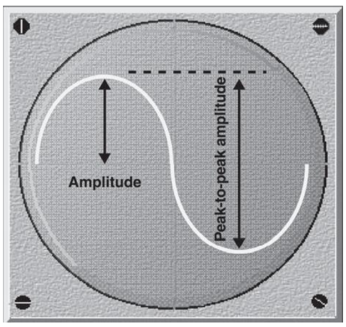
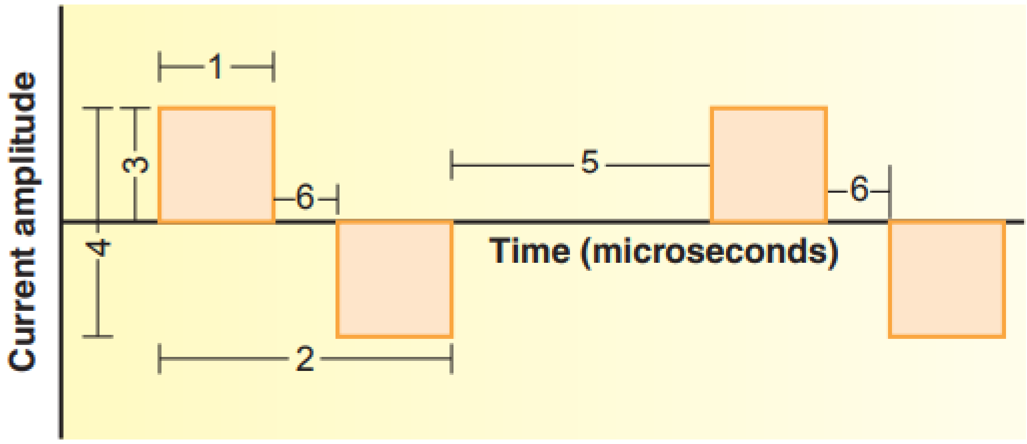


FIG 11-10 Current amplitude.





1. Phase duration
2. Pulse duration
3. Peak amplitude
4. Peak-to-peak amplitude
5. Inter-pulse interval
6. Intra-pulse interval

Fig 9 ■ 15 Amplitude and time (duration) characteristics of pulsed current.

MODULATION OF PULSED CURRENT

- Modulation of pulsed current is widely used in electrotherapeutics to impart a variety of different effects. The duration for which a series of pulses or bursts is delivered is termed the on-time, and the duration or time between a series of pulses or bursts is the off-time. The percentage of the on-time to the total time (on-time plus off-time) multiplied by 100% is termed the duty cycle.

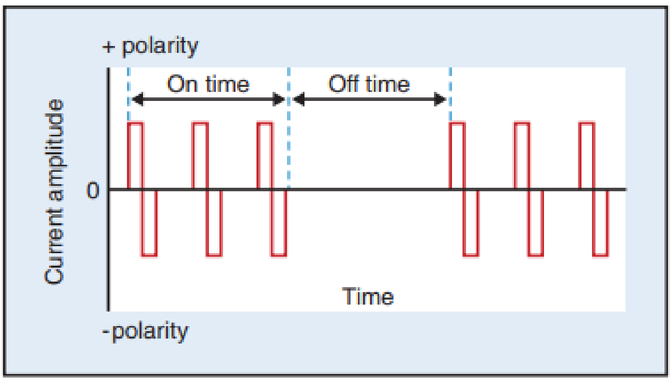


FIG 11-12 On:off times for a biphasic current.

- For example, a clinical application for muscle strengthening may use an on-time of 10 seconds with an off-time of 40 seconds. The duty cycle of this application would be 10 seconds (on-time) divided by 50 seconds (total-time) multiplied by 100%, or 20%.

Amplitude Modulation

- Modulation of the amplitude characteristics of pulsed current is used for differing effects. Often it is necessary to gradually or progressively increase the amplitude of a current to the desired intensity. Take, for example, stimulating muscle. A gradual increase in current amplitude and muscle activation may be more tolerable and ultimately beneficial than a rapid increase and abrupt muscle contraction.
- Ramp refers to the progressive increase or decrease in amplitude. When the amplitude is progressively increased, it is termed ramp-up, and when amplitude is decreased, it is ramp-down. Use of stimulation to facilitate a functional hand grasp–release may incorporate ramp-up and ramp-down to produce a controlled and functional activity.
- The terms rise time and fall time are used to describe the time required for the leading edge of a single phase to reach peak amplitude and the time required for the trailing edge of a single phase to return to the isoelectric line, respectively. Ramps are specific to the increase or decrease in the amplitude of a series of pulses.

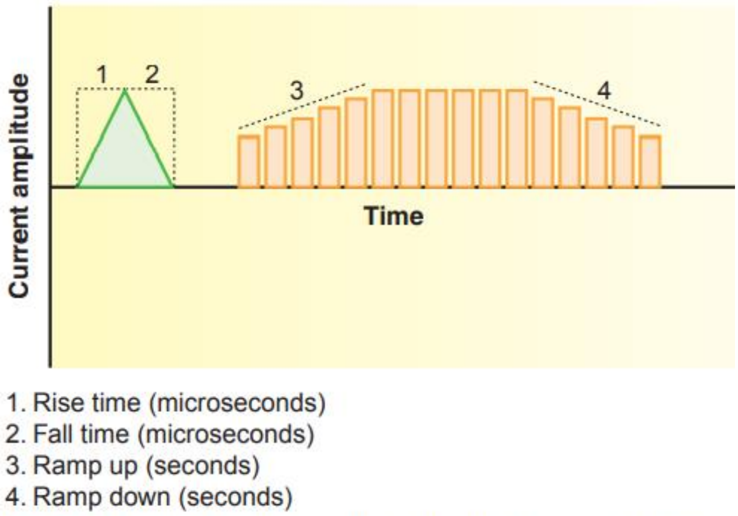


Fig 9 ▪ 16 Amplitude modulation of pulsed current: ramps, rise time, and fall time.

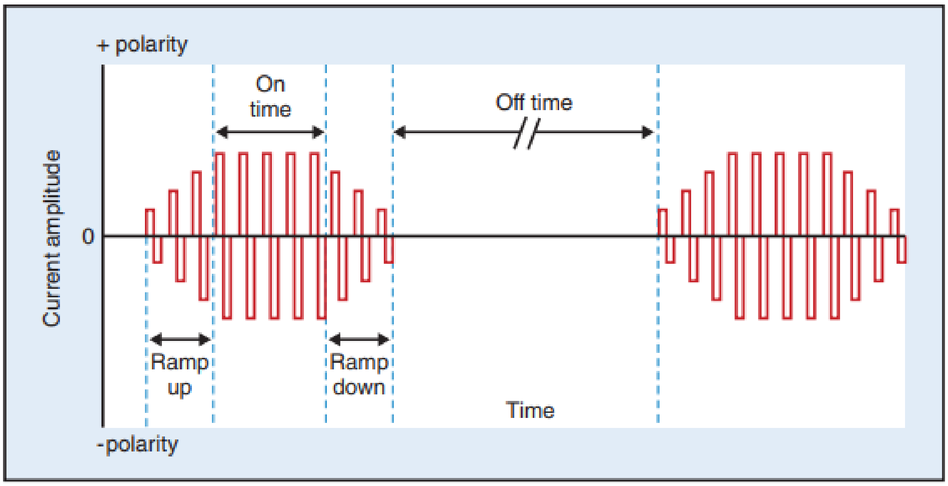


FIG 11-13 Ramp up and ramp down times.

- ***It is important to read the user's manual for electrotherapeutic devices so the clinician understands how ramps are incorporated into the total on- and off-times. For example, some manufacturers include ramp-down time in the off-time. However, this is problematic because current is still being delivered during the rampdown and should be considered on-time.***