MEDICAL UNIVERSITY – PLEVEN
FACULTY OF MEDICINE

DIVISION OF PHYSICS AND BIOPHYSICS

LECTURE 8

ELECTRICAL AND ELECTRONIC INSTRUMENTS

Sensing elements for physiological measurements. Amplifiers. Display devices. The defibrillator. Electrocautery and electrosurgery

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SENSING ELEMENTS

Most of the instruments used for physiological measurements consist of :
(1) sensing element,
(2) an amplifier, and
(3) a display device.

Sensors convert physiological data into small electrical signals. They are also called "transducers."

Advantages of the electrical "image" of physiological data:

- ✓ It can be transmitted to a remote monitoring point
- ✓ It can be amplified if necessary
- ✓ It can be displayed in an appropriate manner

THERMOCOUPLE. A temperature sensor which consists of a junction between two different metals in the form of two tiny wires spot-welded together at one point.

When dissimilar metals are brought together, a contact voltage is generated which is proportional to the temperature of the junction.

For a copper-constantan thermocouple, the voltage output changes are 0.04 mV/°C.

If a complete circuit is made by tying the wires together at both ends, the voltages generated will oppose each other.

If both ends are at the same T, $V_{net}=0$. If one junction is put in an ice-water mixture (T=0°C), $V_{net} \sim T$.

One of the wires can be attached to a sensitive voltmeter. The voltage can be calibrated and converted to a temperature indication on a meter or digital display.

- **Advantages** - accuracy and small size.

Thermocouples can be incorporated in the tip of a hypodermic needle. In the form of probes they can be inserted into the patient's ear and used to record T during surgery.

Oral and rectal thermocouple probes are used, as well.

- **Disadvantages**

1. The need for the second junction in an ice and water mixture (circumvented by calibration at average room T). The reference junction in an ice and water mixture is necessary for extremely accurate temperature measurements.

2. The output is a very small DC voltage (mV). It must be amplified for convenient display, which is much more difficult than the amplification of AC signals.

THE ELECTRICAL RESISTANCE THERMOMETER

Since the thermal agitation of the atoms of a metal increases with temperature, its resistance to current flow increases. This fact is used to construct temperature sensors of platinum wire or tape.

If a constant, controlled voltage is placed across the sensing element, then the current flowing through the sensor can be calibrated in terms of temperature.

This is the **most accurate** temperature sensor used for physiological measurements, but **it cannot be miniaturized** like the thermocouple and thermistor probes.

THE THERMISTOR. It is similar to the resistance thermometer in that R changes with T.
However, *R decreases* with *T increase*.

The resistance of a thermistor may change 4 to 6% per ^{0}C compared to 0.4 % per ^{0}C for a platinum resistance thermometer.

Thermistor can be miniaturized - suitable for probing and implantation.

- More sensitive than the thermocouple and more easily calibrated. Though it doesn't have the extreme accuracy of the platinum resistance thermometers, temperature differences as small as 0.01 °C are measurable.

A thermistor can be incorporated into an AC circuit to obtain an AC signal, which can be amplified more easily and reliably than the DC signal from a thermocouple. This property, along with miniaturization, makes it suitable for use in a telemetering capsule or "radio pill" which can be swallowed or implanted. Temperature data are then transmitted to an external radio receiver.

Thermistors are used in many dialysis machines as safety devices to shut off the dialysate flow if the temperature of the dialysate liquid is outside narrow limits.

A thermistor which is heated by passing I through it can be used to monitor respiration.

If placed in the respiratory air stream, it is cooled by both inspiration and expiration $\longrightarrow$ changed R and I.

Alarm circuitry is triggered to sound an alarm if breathing stops (apnea alarm).

Pressure Transducer

It produces an electrical signal proportional to the pressure exerted upon it.

Microphones can be classified as pressure transducers, since they form an electrical "image" of the pressure variation in the air caused by sound.

Direct blood pressure measurements require access to the circulatory system. For arterial pressure this access is usually in the form of a needle or catheter inserted into the brachial artery at the elbow.

Once the needle or catheter is inserted, the pressure transducer can be placed on the external end of the catheter. The catheter is filled with a saline solution. Since the pressure in the fluid is transmitted undiminished through the catheter (Pascal's law), the pressure at the outer end is an indicator of the arterial pressure.

This type of transducer is referred to as the **"strain-gauge“ transducer.**

The measurement of the pressure in the cavities of the heart requires the use of extremely small catheters called "drift catheters," which are inserted into the venous system and are allowed to drift with the blood flow into the heart.

Two types of transducers for these catheters are used:

1. Very small strain-gauge type transducers are developed which fit on the inserted end of the catheter. Since a current must be passed through this strain-gauge type transducer, this requires a fairly low resistance electrical conductor into the heart, with the consequent problems of electrical safety.

2. Piezoelectric transducer. When a pressure is exerted upon a piezoelectric crystal, a small voltage is generated between the surfaces of the crystal. This voltage is proportional to the pressure and can be calibrated to measure the blood pressure. Small piezoelectric transducers can be mounted on the ends of small catheters and inserted into the heart cavities. They produce small voltages.

Advantage - a voltage need not be applied to them, but they must nevertheless be used with caution since the measuring wires represent an electrical conducting path to the heart and make the patient micro shock-sensitive.

THE OXIMETER. It uses light for determining the oxygen content of the blood (**oxygen content** - the percentage of oxygen saturation of hemoglobin).

Procedure: A small sample of blood is illuminated with red light, and the reflected light from the blood enters a photoelectric cell. The amount of light reflected depends upon the oxygen saturation of Hb.

The reflection **is independent of the total Hb** and is determined **by the ratio of oxyHb to Hb.**

The photoelectric cell produces **a small DC voltage** ~ to the light intensity. The voltage can be amplified, calibrated, and used to display the oxygen saturation percentage on a meter or recorder.

Electrodes for pH, P_{CO_2} and P_{O_2}.

- ✓ The most important parameters related to blood chemistry.
- ✓ Their determination requires sophisticated techniques.
- ✓ Sensors have been developed which can provide electrical signals.

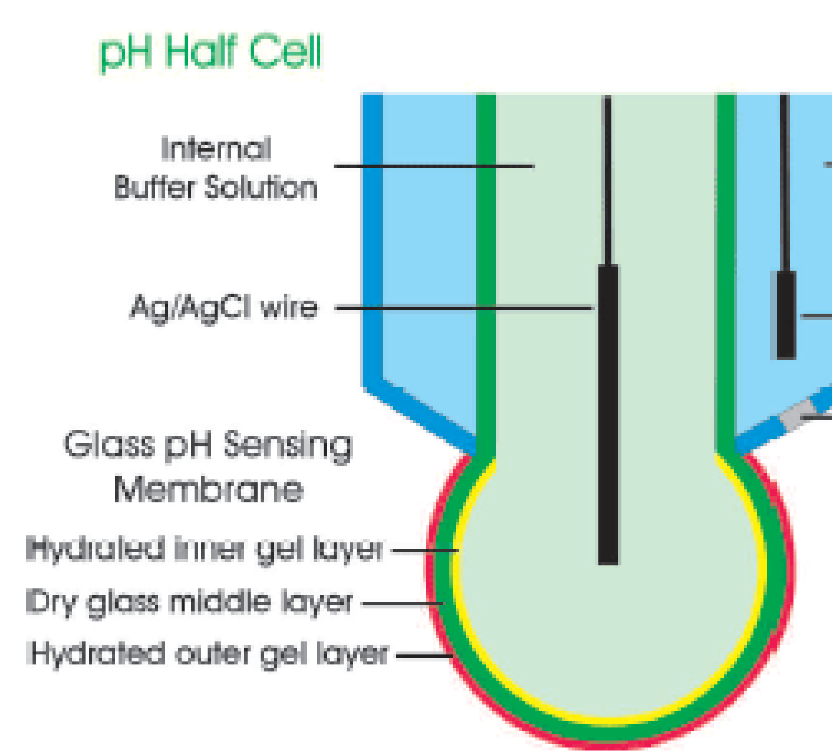


Figure 1 Typical combination pH electrode

A pH electrode consists of a small glass bulb which is selectively permeable to hydrogen ions.

Inside the bulb is a silver electrode which is coated with silver chloride and immersed in a buffer solution with pH = 1.

When the electrode is placed in a liquid of unknown pH, the diffusion process across the permeable glass "membrane" produces a small voltage on the electrode. This voltage can be calibrated and used to determine pH.

The pH of the blood depends upon Pco_2. A modified pH electrode can be used to measure Pco_2 .

This is done by determining the pH of the blood and then making two additional pH determinations on the blood sample after it has been allowed to come to equilibrium with gases of known Pco_2, for example 30 and 60 mm Hg. Since the blood Pco_2 will normally lie between these partial pressures, it can be determined graphically by **interpolation.**

AMPLIFIERS

- The electrical output of most transducers is much too small to be displayed directly.
- The amplifier must produce **a distortion-free replica** of the original signal so that none of the information is lost.

TRIODES AND TRANSISTORS. The *transistor* is the basic active element in most amplifiers.

Modern amplifiers use **solid-state integrated circuits** (ICTs), which are miniaturized elements containing many transistors.

ICTs have contributed greatly to the **miniaturization**, **reliability**, and **sturdiness** of modern electronic components.

Transistors have superseded the older vacuum tube amplifiers. The vacuum tube triode is easier to visualize and can serve as an aid for understanding the transistor. The triode vacuum tube contains a cathode, an anode and a grid.

The cathode is heated to temperatures at which it gives off electrons by a process called thermionic emission. As the electrons are given off, they are attracted by the positive electrode and move "downhill", causing a current to flow through the tube.

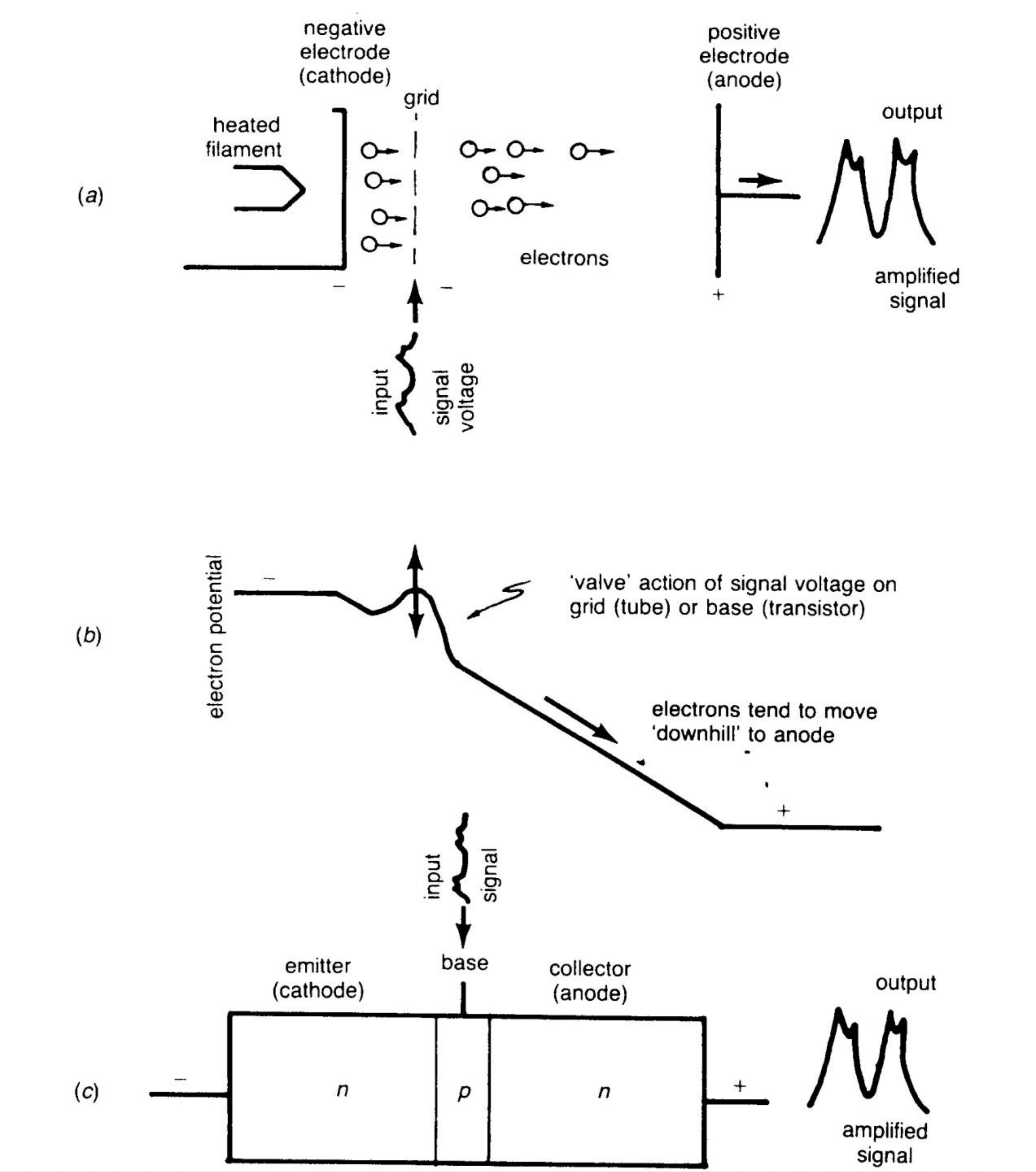
If the grid is given a negative potential, it forms a repulsive barrier which the electrons must surmount before they can move to the anode.

Since the grid is close to the cathode, a small negative potential can stop the flow of electrons through the tube.

The grid acts as the control element in an electrical "valve" which controls the large flow of charge through the triode. The current through the tube can be very large.

- The small signal from the physiological data transducer is placed on the grid. The voltage output from the tube forms a large electrical replica of the small input voltage on the grid.

This valve action accomplishes the desired amplification of the input signal.


negative electrode (cathode)
grid
heated filament
(a)
electrons
positive electrode (anode)
output
amplified signal
input signal voltage
(b)
electron potential
'valve' action of signal voltage on grid (tube) or base (transistor)
electrons tend to move 'downhill' to anode
input signal
(c)
emitter (cathode)
base
collector (anode)
n
p
n
output
amplified signal

Several tubes can be placed in sequence so that the output of the one tube is applied to the grid of the successive tube (amplification by factors of several million). Practical limits are set by electrical **"noise"** and **distortion**.

- The transistor is **the solid-state analog** to the triode vacuum tube. It also amplifies small electrical signals by a valve type control. The mechanism is quite different. The conductivity of Si and Ge depends upon a small percentage of "impurity" elements such as antimony and indium introduced by controlled diffusion during the manufacturing process.

Antimony → excess electrons → n-type semiconductor

Indium → deficiency of electrons → p-type semiconductor

If a thin layer of one type of semiconductor is sandwiched between two layers of the opposite type, the result is a **transistor**.

These three elements of the transistor are called the **emitter** (*cathode*), **base** (*grid*), and **collector** (*anode*).

If the collector is given a positive voltage with respect to the emitter, electrons tend to move across the thin base region to the collector.

A small controlling voltage on the base region can cause large variations in the emitter-to-collector current. This valve action accomplishes the amplification of the signal as described above.

DISPLAY DEVICES

The numerical values in physiological data are usually taken from a display device such as an oscilloscope, a meter, a chart recorder, or a digital display device.

THE OSCILLOSCOPE. The cathode-ray oscilloscope is an extremely versatile display device for monitoring physiological data.

The oscilloscope can be used to display voltages from DC to very high frequency AC.

- Its particular advantages stem from the visual display of the voltage as it varies with time, rather than just a measurement of the average voltage.

It is used as a cardiac monitor, since the repetition rate and the detailed shape of the ECG voltage pattern are of interest.

Multiple displays on a single oscilloscope screen may be obtained either by using multiple electron guns at the back of the tube or by electronically switching a single beam at a very high rate so that a single beam produces several separately controlled displays.

- In this way a single oscilloscope can monitor several physiological variables simultaneously - **systolic and diastolic P**, **pulse rate**, **respiration**, **ECG**, ect.

Meters and Chart Recorders. The principle of operation of the **moving coil meter** is based upon the fact that a current-carrying wire will experience a force proportional to the current if placed in a magnetic field.

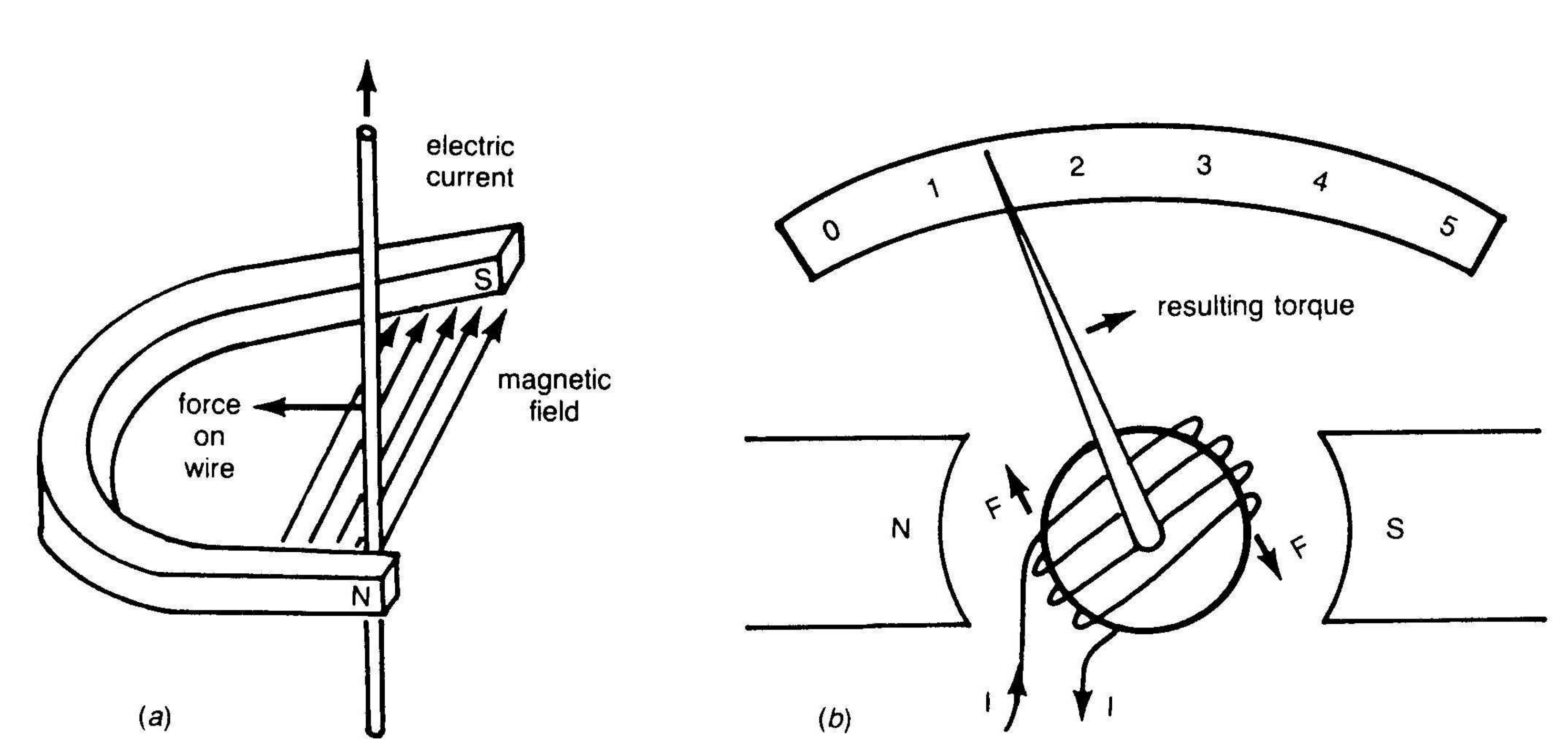
If a coil of wire is placed in the magnetic field, a force will be exerted on both sides of the coil. This will cause a **torque** which tends to **rotate** the coil.

The torque is proportional to the current through the coil. If an indicating "needle" or pointer is attached to the coil, **the position of the pointer can be calibrated in terms of the current.**

This basic arrangement is called a galvanometer - the basis for all types of moving coil meters. The moving coil meter is basically a current measuring device, but since both voltage and resistance are related to current by Ohm's law, it can be adapted to measure voltages or resistances.

If a large resistor is placed in series with the coil, the combination can be used as a voltmeter, since the current flowing through the coil will be proportional to the voltage across the combination.

If a battery of known voltage is connected in series with the coil, then it can be used as an ohmmeter.



The principle of the moving-coil meter, (a) A current-carrying wire will experience F when placed in a magnetic field; (b) a coil placed in a magnetic field will experience a torque which is proportional to the I flowing in the coil.

By including a battery and a series of calibrated resistors, a single moving coil can be used for **multiple functions**.

When a permanent record of an electrical signal as a function of time is required, the **chart recorder** is the logical display device. Paper from a roll is moved at a constant linear speed while an indicator pen makes a continuous record of an electrical signal. The motion of the pen perpendicular to the paper travel is proportional to the applied signal voltage or current.

- Limitations of the chart recorder - **slowness of response.**

DIGITAL DISPLAYS

Light-emitting diode (LED) and liquid crystal diode (LCD) displays seem to be the most practical for biomedical applications.

- They are small, rugged, and dependable and are easily interfaced to amplification circuits. Once the electrical signal is converted to digital form, it is easier to add logic or computing circuitry to perform other useful functions.

THE DEFIBRILLATOR

Defibrillator – a high voltage device, a standard item of emergency equipment in the hospital.

A small electric current through the heart can cause ventricular fibrillation, but a much larger current can cause a sustained ventricular contraction.

When life-threatening ventricular fibrillation occurs from any cause, a momentary large current flow through the heart stops the fibrillation and the normal heart rhythm will often resume when the current is stopped. This rather severe method has proved to be quite successful in interrupting the random, chaotic activity of the heart cells.

- The defibrillator is basically a large capacitor. It is similar in principle to the parallel plate configuration. Charge is stored on the plates of the capacitor by a high voltage, usually around 7500V but sometimes as high as 10^4 V.

  When the electrodes are placed on the patient's chest and the switch is closed, the capacitor discharges through the patient's body.

  Duration of discharge current - a few ms.

  The capacitor must recharge for several seconds before it can be used again. The defibrillator is used for emergency resuscitation from a heart stoppage or ventricular fibrillation. The currents produced, although brief, are high enough to be hazardous.

ELECTROCAUTERY AND ELECTROSURGERY

Electrosurgical instruments are used extensively for either cutting tissue or welding tissue together. These instruments generate high frequency currents at voltages up to 1.5×10^4 V. The physiological effects of electric currents are strongly dependent upon the frequency. The current could be lethal if f=60Hz, depending upon the path through the body.

- High frequencies do not cause ventricular fibrillation in normal usage, and the **possibility of burns** is the main electrical danger. The body is most susceptible to shock in the region from 10 to 100 Hz, and the sensitivity drops off quite rapidly for high frequencies.

When the high frequency voltage is applied to a sharp metal probe or blade, it becomes an effective cutting tool.

f ~ 500 to 600 kHz are effective for cutting operations,

f ~ 2 to 4 MHz are more effective for coagulation and cautery.

The high current density caused by several amperes of current entering the body through the small area of the probe accounts for the cutting and cauterizing action.

Precautions must be taken to ensure that the current doesn't leave the body through a small area, since that would cause severe burns at the exit point. A large conducting buttock plate is usually placed under the patient to provide a large area for the exit current.