

# CATELECTROTONUS

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## Catelectrotonus

**Primary Disciplinary Field(s):** Neurophysiology, Electrophysiology, Biomedical Engineering

### 1. Core Definition

**Catelectrotonus** is a fundamental neurophysiological phenomenon defined as the increased excitability or irritability observed in an excitable tissue, such as a nerve fiber or muscle cell, localized specifically in the region nearest the negative electrode, or the **cathode**, when a weak, steady electrical current is passed through the tissue. This condition represents one half of the broader phenomenon known as **electrotonus**, which describes the passive changes in membrane potential that spread along the length of an axon or fiber in response to a subthreshold electrical stimulus. The defining characteristic of catelectrotonus is a shift in the membrane potential toward a less negative, or **depolarized**, state, thus bringing the tissue closer to its threshold for generating an action potential.

The physiological consequence of this localized depolarization is an immediate and observable increase in the readiness of the tissue to respond to subsequent stimuli. If the applied current is sufficient to push the membrane potential past the excitation threshold at the cathode, a propagated action potential will be initiated. However, catelectrotonus itself refers specifically to the graded, non-propagated potential change that occurs before this threshold is reached. It is a passive electrical response governed by the intrinsic cable properties of the excitable membrane, including its resistance and capacitance. This effect contrasts sharply with the state observed at the positive electrode (the anode), termed **anelectrotonus**, where the membrane becomes hyperpolarized and less excitable.

Understanding catelectrotonus is crucial for interpreting the behavior of nerves and muscles under the influence of external electric fields. Unlike active changes in potential, such as the action potential which is regenerative and "all-or-nothing," catelectrotonic potentials are additive and proportional to the intensity of the applied current. They spread decrementally away from the stimulating electrode, meaning their amplitude diminishes exponentially with distance, a spread governed by the membrane's characteristic length constant. The localized nature and graded response make catelectrotonus a vital concept in modeling neural integration and the passive spread of current in dendrites and axons.

### 2. Etymology and Historical Development

The concept of electrotonus, encompassing both the catelectrotonic and anelectrotonic states, has roots extending back to the pioneering era of **bioelectricity** in the late 18th century, initiated by figures like Luigi Galvani and Alessandro Volta. However, the systematic scientific investigation

and formal naming of these phenomena occurred in the mid-19th century, primarily through the work of German physiologists. The term **electrotonus** was formalized by Emil Du Bois-Reymond, often considered the father of modern electrophysiology, who meticulously studied the electrical properties of nerves using highly sensitive galvanometers.

The term **Catelectrotonus** derives from Greek roots: *kata-* (meaning "down" or "against," often used to denote direction toward the lower potential, the cathode), *electron* (referring to electricity or amber), and *tonos* (meaning "tension" or "stretching," referring to the state or tension of the tissue). Thus, the term literally describes the state of electrical tension or change that occurs near the cathode. Du Bois-Reymond's experiments demonstrated that applying a direct current to a section of a nerve modified the nerve's excitability in a spatially specific manner, paving the way for quantitative analysis of membrane potential changes induced by external current injection.

The critical historical insight was recognizing that the application of a current did not uniformly affect the entire nerve; rather, it created distinct regions of altered excitability corresponding to the polarity of the applied electrodes. This discovery was central to establishing the electrical nature of nerve conduction and contributed directly to the development of the **cable theory** of axons, which mathematically describes how electrotonic potentials spread through biological conductors. Modern electrophysiology, utilizing microelectrodes and voltage clamp techniques, has confirmed these classical observations, allowing precise measurement of the ion fluxes and potential shifts that underlie the catelectrotonic state.

### 3. Key Characteristics and Biophysical Mechanism

The biophysical mechanism underlying **catelectrotonus** is rooted in the movement and accumulation of ions across the semi-permeable cell membrane in response to the injected direct current. When the negative electrode (cathode) is placed near the tissue, the external circuit draws positive current away from this region. Since current is conventionally defined as the flow of positive charge, the cathode acts as a sink for positive charge in the extracellular space immediately adjacent to the membrane.

This removal of positive charge from the exterior surface effectively reduces the potential difference across the membrane. The resting membrane potential is maintained by a higher concentration of positive ions (primarily Na<sup>+</sup>) outside and a higher concentration of negative ions (primarily organic anions and K<sup>+</sup>) inside. By making the exterior less positive relative to the interior, the cathode induces **depolarization**. This passive change results in a decrease in the magnitude of the membrane potential ( $V_m$  becomes less negative), moving it closer to the threshold required to open voltage-gated sodium channels. This partial depolarization constitutes the state of increased excitability known as catelectrotonus.

The spatial characteristics of catelectrotonus are defined by the length constant ( $\lambda$ ) of the

nerve fiber. The length constant is a measure of how far an electrotonic potential can spread before its amplitude decays to 37% of its initial value at the source. Tissues with larger diameters and higher internal resistance relative to membrane resistance (i.e., higher myelination) possess longer length constants, allowing the catelectrotonic effect to spread over a greater distance. Conversely, the time course of the establishment and decay of catelectrotonus is governed by the time constant ( $\tau$ ), which reflects the inherent capacitance and resistance of the membrane itself. These passive properties dictate that the establishment of the maximal catelectrotonic state is not instantaneous but requires a brief period of time.

#### 4. Comparison with Anelectrotonus

To fully appreciate **catelectrotonus**, it must be contrasted with its reciprocal phenomenon, **anelectrotonus**, which occurs at the positive electrode, the **anode**. While catelectrotonus involves depolarization and increased excitability, anelectrotonus involves the opposite: **hyperpolarization** and decreased excitability.

At the anode, the external circuit injects positive current into the extracellular space surrounding the nerve or muscle fiber. This accumulation of positive charge on the exterior surface increases the potential difference across the membrane (making the exterior even more positive relative to the interior). Consequently, the membrane potential becomes more negative (hyperpolarized), moving it farther away from the threshold for excitation. This state reduces the likelihood of the tissue firing an action potential, effectively stabilizing or inhibiting the tissue.

The physiological difference between the two states is profound. Catelectrotonus facilitates the initiation of activity, making the tissue hypersensitive, which is why when a strong direct current is applied, excitation typically occurs when the current is turned on (make) at the cathode. Anelectrotonus, by contrast, suppresses activity, and excitation is typically observed when the current is turned off (break) at the anode, due to the rapid rebound depolarization caused by the abrupt cessation of the hyperpolarizing current. Both phenomena demonstrate the fundamental principle that externally applied electrical fields modulate the intrinsic excitability of biological membranes in a polarity-dependent manner.

#### 5. Clinical and Experimental Significance

The principles governing **catelectrotonus** are not confined to laboratory models but have significant implications for experimental neurobiology and clinical interventions. Experimentally, the study of electrotonic potentials allows researchers to probe the passive electrical properties of neurons without triggering active action potentials, providing critical data for constructing accurate models of neuronal integration, particularly in dendrites where most synaptic inputs produce graded electrotonic potentials. Measuring the spatial spread of catelectrotonic potentials is the

primary method for determining the crucial length constant of a fiber.

In clinical settings, the depolarizing effect of the cathode is exploited in therapeutic modalities, most notably in **Transcranial Direct Current Stimulation (tDCS)**. Although the application is complex due to the intervening skull and meninges, tDCS operates by applying low-intensity direct currents to the scalp to modulate cortical excitability. The placement of the cathode (cathodal stimulation) over a target cortical area generally induces hyperpolarization (similar to anelectrotonus, but the effect is often termed "cathodal" when referring to the stimulation site), leading to a decrease in cortical excitability--a seemingly contradictory effect that arises because the current flow orientation relative to the underlying neuronal geometry is complex and often reverses or shunts the predicted surface effect. However, the direct stimulation of peripheral nerves or muscles always adheres to the principle: the region near the cathode experiences **catelectrotonus**, facilitating muscle contraction or nerve firing.

Furthermore, catelectrotonus plays a role in diagnostic procedures, such as determining nerve and muscle health via excitability tests. The ability of a muscle or nerve to respond preferentially near the cathode when an electrical pulse is applied (known as the Law of Excitation) is a critical indicator of functional membrane integrity. If the tissue fails to show the expected increase in excitability at the cathode, it suggests underlying pathology affecting membrane properties or ionic balance.

## 6. The Law of Excitation and Current Strength

The phenomena of catelectrotonus and anelectrotonus are mathematically unified under the general framework of electrotonic spread, but their physiological manifestation is described by the classical **Law of Excitation** (sometimes called Pflüger's Law). This law dictates the conditions under which an action potential is generated when a direct current is applied to a nerve. The law states that excitation (the "make" or onset of an action potential) occurs primarily at the cathode (due to **catelectrotonus**) when the current is switched on, provided the current strength is sufficient.

The relationship between current strength and the level of catelectrotonus is linear: a stronger current produces a greater degree of depolarization at the cathode. However, the critical factor is the relationship between the resulting depolarization and the excitation threshold. Weak currents produce subthreshold catelectrotonus that merely increases excitability; they do not cause firing. Only when the current is strong enough to drive the catelectrotonic depolarization past the threshold potential will an action potential be initiated. This critical minimum current intensity required to elicit a response is known as the **rheobase**.

Moreover, the duration for which the current is applied (chronaxie) interacts with the magnitude of the catelectrotonus. A very brief but intense current can achieve the threshold rapidly, while a

weaker current requires a longer duration to allow the membrane capacitance to charge fully to the required potential, illustrating the time-dependent nature of achieving the fully developed catelectrotonic state. The Law of Excitation, therefore, provides a systematic framework linking the passive catelectrotonic response to the active firing properties of excitable cells.

### Further Reading

[Electrotonus \(Wikipedia\)](#)

[Depolarization \(Wikipedia\)](#)

[Cable Theory \(Wikipedia\)](#)

[Transcranial Direct Current Stimulation \(tDCS\) \(Wikipedia\)](#)

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