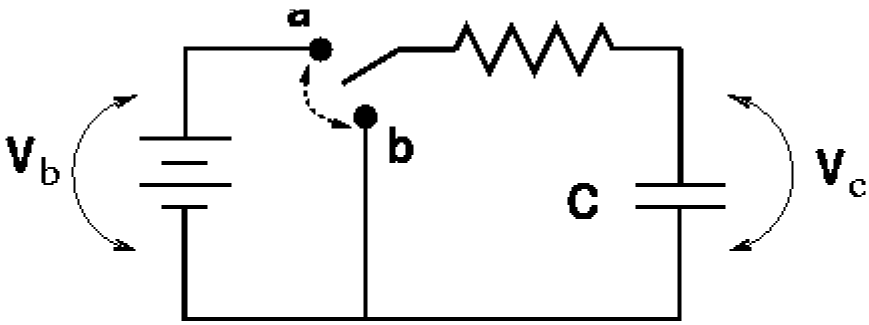
How does a RC circuit work, especially the charges on the capacitor?

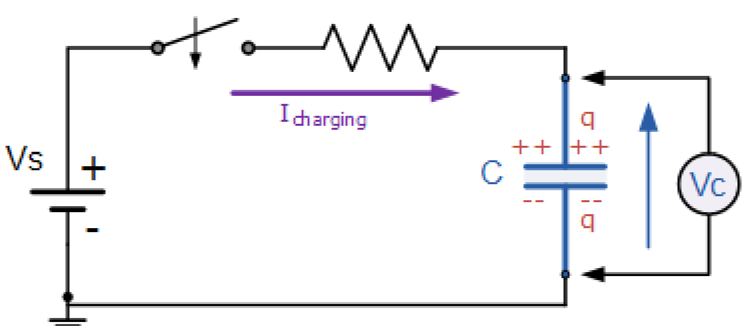
The current always flows always out from $+V_b$ terminal of the voltage source, passes through the circuit and then enters back in voltage source through its -ve terminal.



Refer figure above. When the switch is turned on by bringing it to position "a", resister gets connected to $+V_b$ of the battery. Current starts flowing out of the $+V_b$ terminal of the battery, flows through R and C, and enters back in $-V_b$ terminal of the battery. In this process, capacitor gets charged with resistor side of the capacitor becoming positive.

When the switch is turned off by bringing it to position b, capacitor starts discharging. Now the capacitor acts as a voltage source. As resistor side terminal of the capacitor is positive, current starts flowing out of the same terminal, passes through the resistor, through terminal B of the switch and enters back in $-V_b$ side of the switch.

RC Charging Circuit



All Electrical or Electronic circuits or systems suffer from some form of "time-delay" between its input and output, when a signal or voltage, either continuous, (DC) or alternating (AC) is firstly applied to it. This delay is generally known as the **time delay** or **Time Constant** of the circuit and it is the time response of the circuit when a step voltage or signal is firstly applied.

The resultant time constant of any electronic circuit or system will mainly depend upon the reactive components either capacitive or inductive connected to it and is a measurement of the response time with units of, **Tau – τ

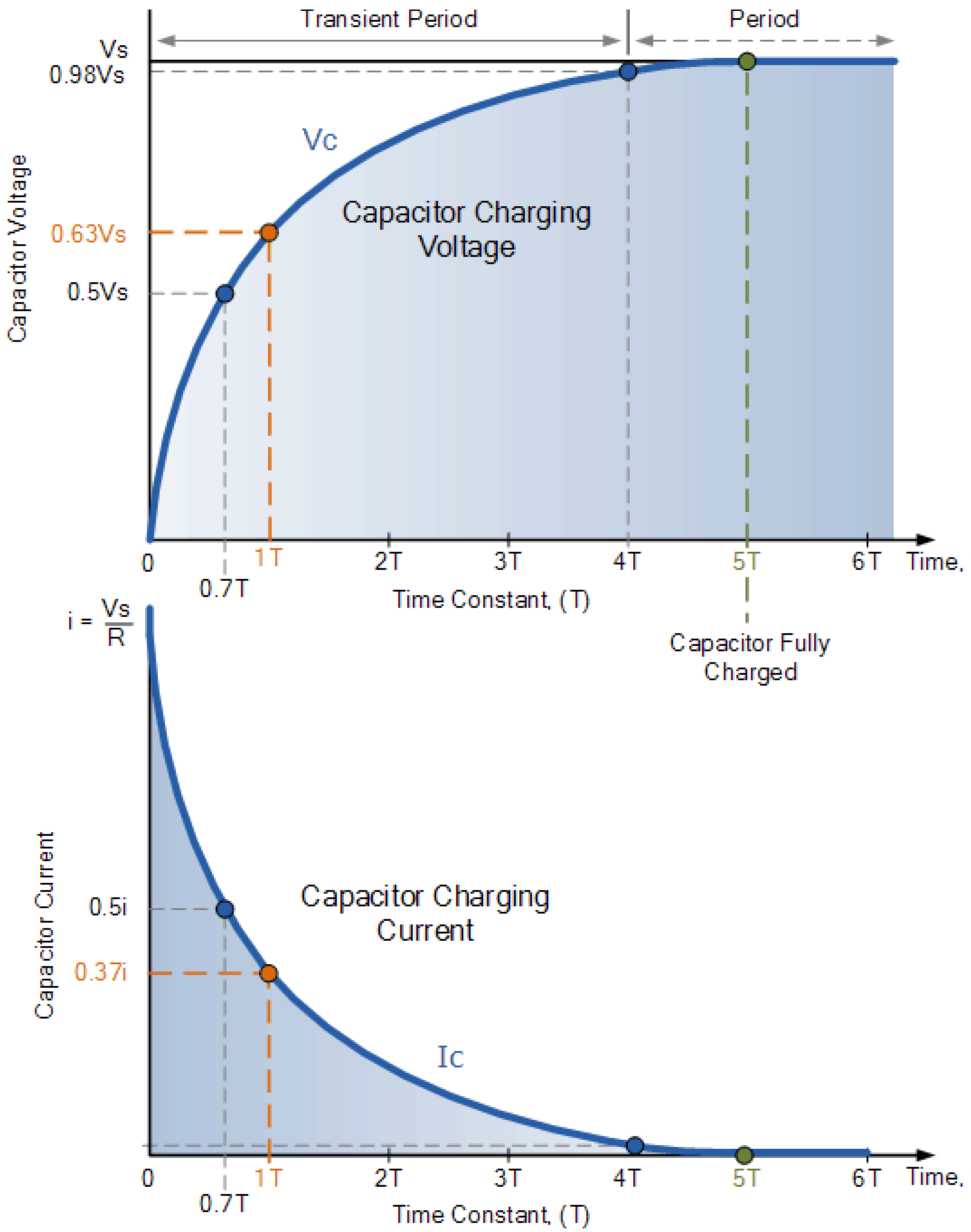
When an increasing DC voltage is applied to a discharged Capacitor, the capacitor draws a charging current and “charges up”, and when the voltage is reduced, the capacitor discharges in the opposite direction. Because capacitors are able to store electrical energy they act like small batteries and can store or release the energy as required.

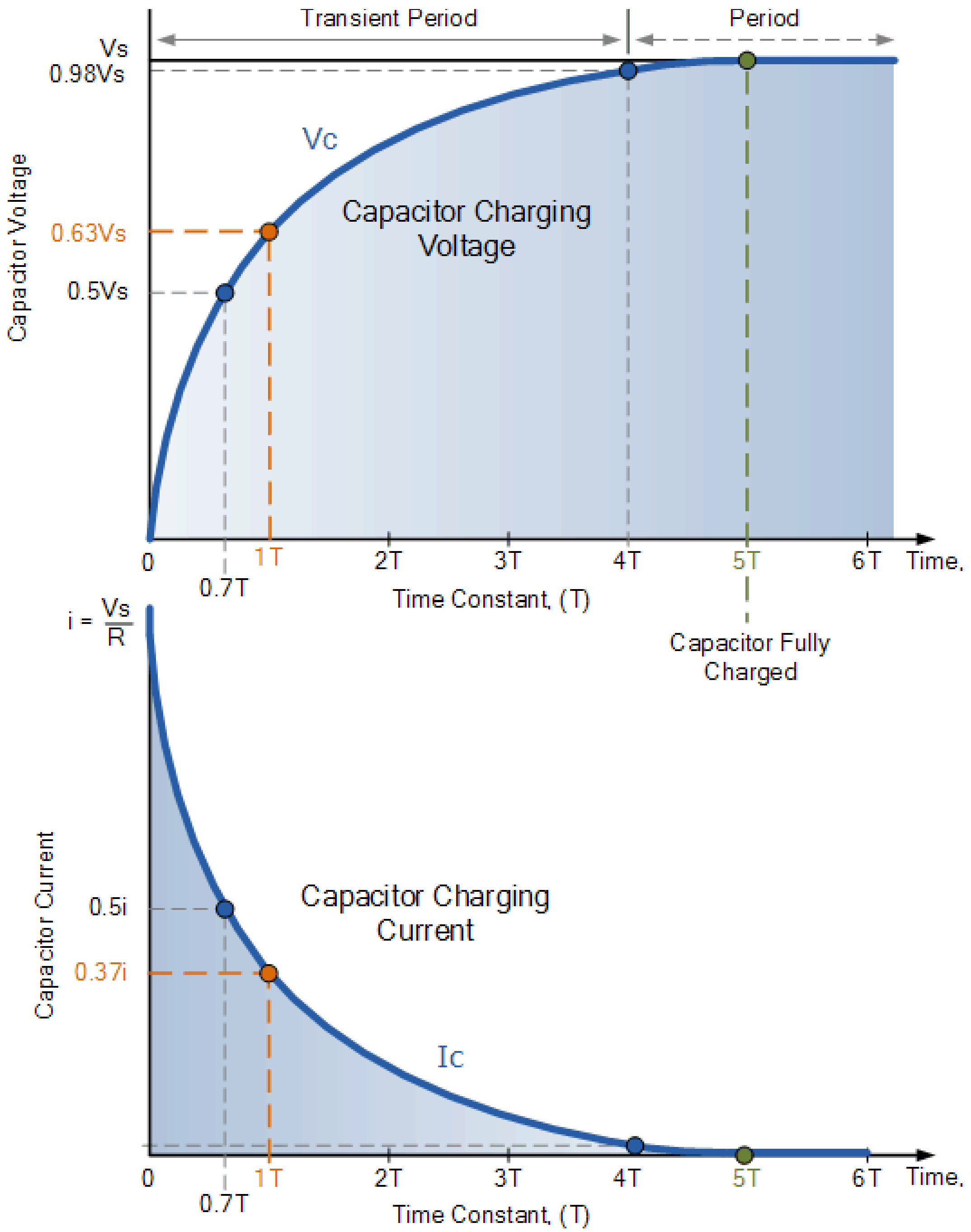
The charge on the plates of the capacitor is given as: Q = CV. This charging (storage) and discharging (release) of a capacitors energy is never instant but takes a certain amount of time to occur with the time taken for the capacitor to charge or discharge to within a certain percentage of its maximum supply value being known as its **Time Constant** (τ).

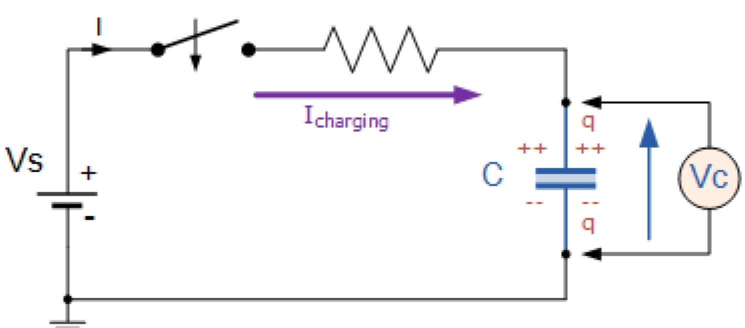
If a resistor is connected in series with the capacitor forming an RC circuit, the capacitor will charge up gradually through the resistor until the voltage across the capacitor reaches that of the supply voltage. The time also called the transient response, required for the capacitor to fully charge is equivalent to about **5 time constants** or 5T.

This transient response time T, is measured in terms of τ = R x C, in seconds, where R is the value of the resistor in ohms and C is the value of the capacitor in Farads. This then forms the basis of an RC charging circuit were 5T can also be thought of as “5 x RC”.

RC Charging Circuit Curves




Transient Period
Period
Vs
0.98Vs
Capacitor Voltage
Vc
0.63Vs
Capacitor Charging
Voltage
0.5Vs
0
0.7T
1T
2T
3T
4T
5T
6T
Time, t
Time Constant, (T)
Capacitor Fully
Charged
i = Vs/R
Capacitor Current
0.5i
Capacitor Charging
Current
0.37i
Ic
0
0.7T
1T
2T
3T
4T
5T
6T
Time, t
Time Constant, (T)


I
Icharging
Vs
+
-
C
++
++
--
--
q
q
Vc

Let us assume above, that the capacitor, C is fully “discharged” and the switch (S) is fully open. These are the initial conditions of the circuit, then t = 0, i = 0 and q = 0. When the switch is closed the time begins at t = 0 and current begins to flow into the capacitor via the resistor.

Since the initial voltage across the capacitor is zero, (Vc = 0) the capacitor appears to be a short circuit to the external circuit and the maximum current flows through the circuit restricted only by the resistor R. Then by using Kirchoff’s voltage law (KVL), the voltage drops around the circuit are given as:

$$V_S - R \times i(t) - V_C(t) = 0$$

The current now flowing around the circuit is called the **Charging Current** and is found by using Ohms law as: i = Vs/R.

The capacitor now starts to charge up as shown, with the rise in the RC charging curve steeper at the beginning because the charging rate is fastest at the start and then tapers off as the capacitor takes on additional charge at a slower rate.

As the capacitor charges up, the potential difference across its plates slowly increases with the actual time taken for the charge on the capacitor to reach 63% of its maximum possible voltage, in our curve0.63Vs being known as one Time Constant, (T).

This 0.63Vs voltage point is given the abbreviation of 1T, (one time constant).

The capacitor continues charging up and the voltage difference between Vs and Vc reduces, so to does the circuit current, i. Then at its final condition greater than five time constants (5T) when the capacitor is said to be fully charged, t = ∞, i = 0, q = Q = CV. Then at infinity the current diminishes to zero, the capacitor acts like an open circuit condition therefore, the voltage drop is entirely across the capacitor.

So mathematically we can say that the time required for a capacitor to charge up to one time constant, (1T) is given as:

RC Time Constant, Tau

$$\tau \equiv R \times C$$

This RC time constant only specifies a rate of charge where, R is in Ω's and C in Farads.

Since voltage V is related to charge on a capacitor given by the equation, Vc = Q/C, the voltage across the value of the voltage across the capacitor (Vc) at any instant in time during the charging period is given as:

$$Vc = Vs\left(1 - e^{-t/RC}\right)$$

- Where:
- Vc is the voltage across the capacitor
- Vs is the supply voltage
- t is the elapsed time since the application of the supply voltage
- RC is the *time constant* of the RC charging circuit

After a period equivalent to 4 time constants, (4T) the capacitor in this RC charging circuit is virtually fully charged and the voltage across the capacitor is now approx 98% of its maximum value,0.98Vs. The time period taken for the capacitor to reach this 4T point is known as the **Transient Period**.

After a time of 5T the capacitor is now fully charged and the voltage across the capacitor, (Vc) is equal to the supply voltage, (Vs). As the capacitor is fully charged no more current flows in the circuit. The time period after this 5T point is known as the **Steady State Period**.

Then we can show in the following table the percentage voltage and current values for the capacitor in a RC charging circuit for a given time constant.