



# 3

**3.1**

**3.2**

**3.3**

**3.4**

**3.5**



**3**

- 1.**
- 2.**
  
- 3.**
- 4.**

**3**



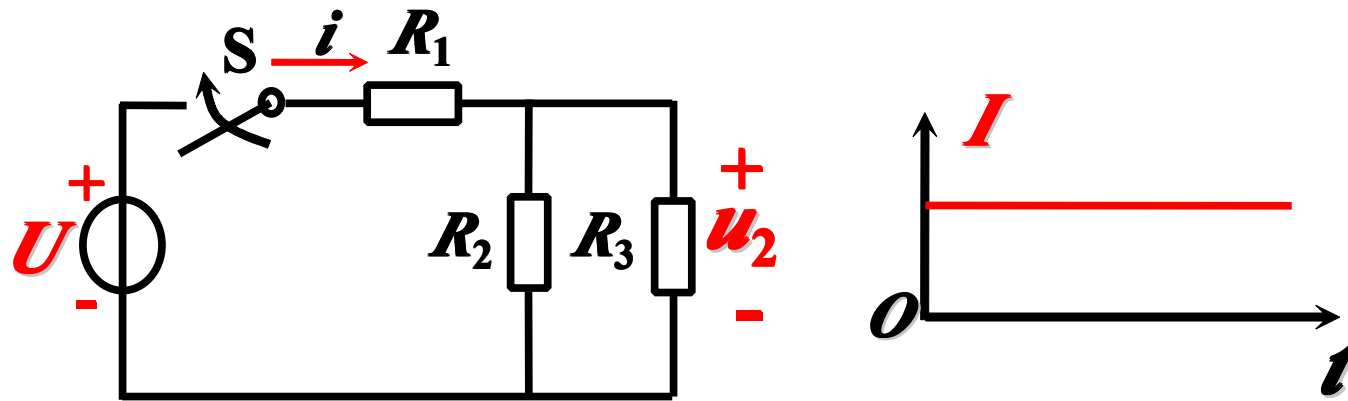
**1.**

**2.**

# 3.1



## 3.1.1

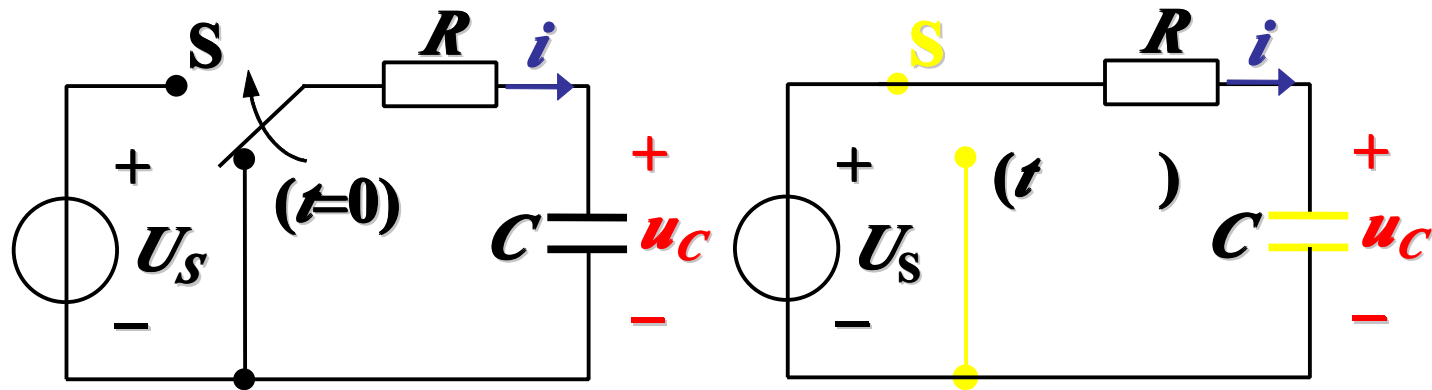


(a)

(a)      S       $i = 0$        $u_{R1} = u_{R2} = u_{R3} = 0$

S       $i$        $u$

(R      )

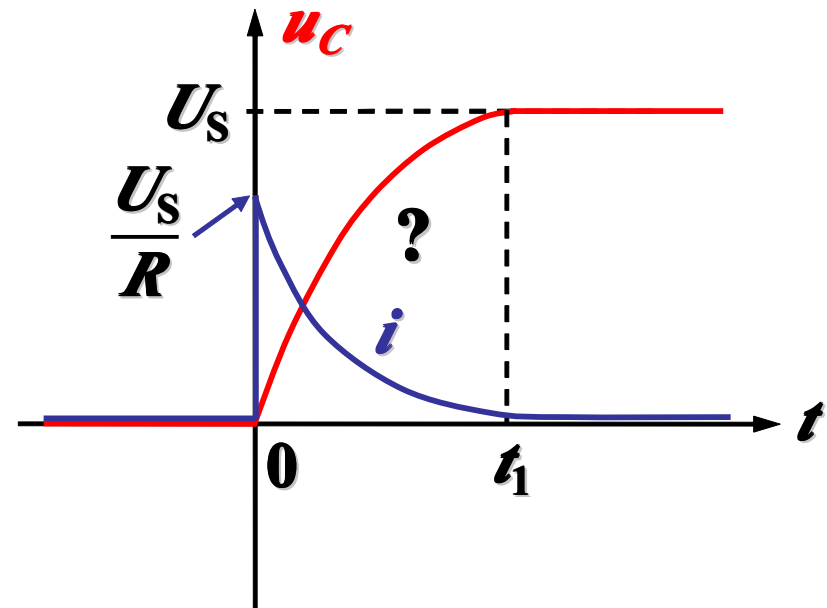


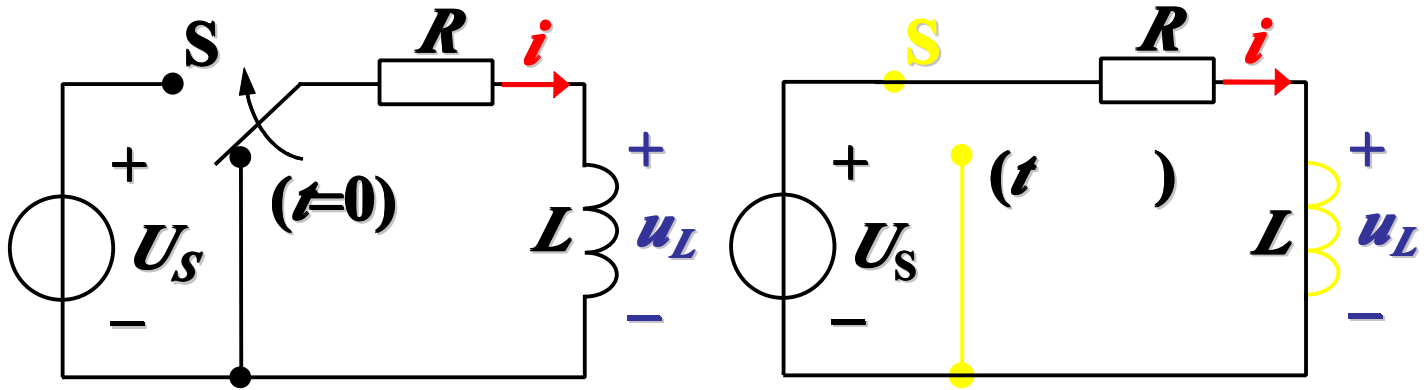
**S**

$$i = 0, u_C = 0$$

**S**

$$i = 0, u_C = U_s$$



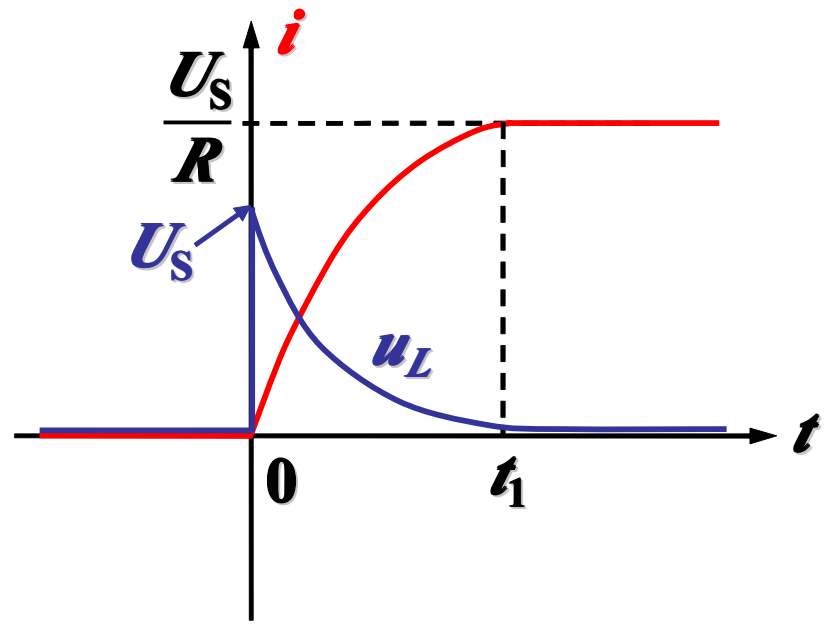


**S**

$$i = 0, u_L = 0$$

**S**

$$u_L = 0, i = \frac{U_s}{R}$$





⋮

***C***

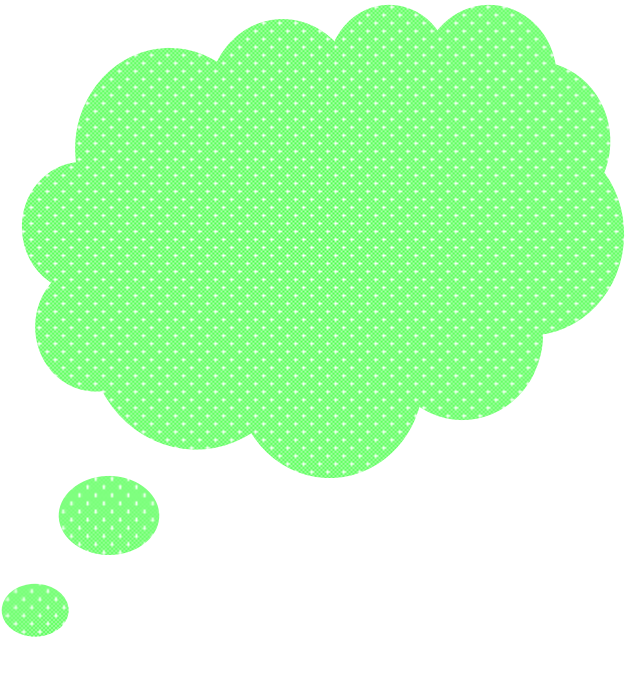
$$W_C = \frac{1}{2} C u_C^2$$

∴ ***u<sub>C</sub>***

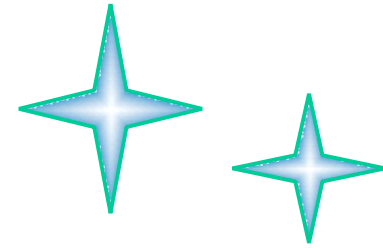
***L***

$$W_L = \frac{1}{2} L i_L^2$$

∴ ***i<sub>L</sub>***



### 3.1.2



$t=0$  —

( )

$t=0_-$  —

$t=0_+$  —

$t=\infty$  —

$$i_L(0_+) = i_L(0_-)$$

$$u_C(0_+) = u_C(0_-)$$

$u_C$   $i_L$



### 3.1.3



$$u \quad i \quad t=0_+$$

$$(1) \quad u_C(0_+) \quad i_L(0_+)$$

$$1) \quad t=0_- \quad u_C(0_-) \quad i_L(0_-)$$

$$2) \quad u_C(0_+) \quad i_L(0_+)$$

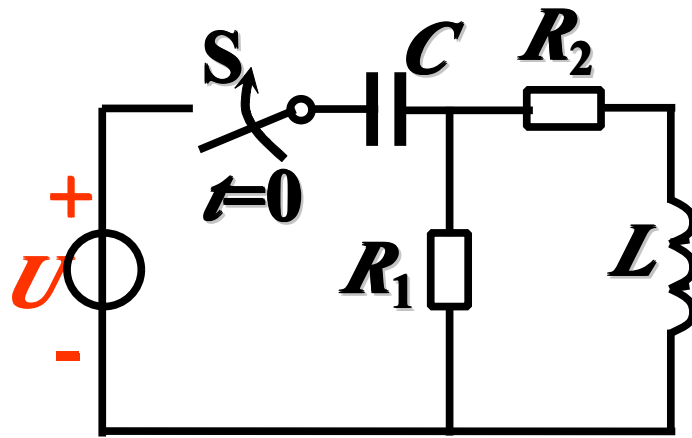
(2)

$$1) \quad t=0_+$$

$$2) \quad t=0_+ \quad u_C = u_C(0_+)$$

$$t=0_+ \quad i_L = i_L(0_+)$$

1



(a)

(1)

$$u_C(0_-), i_L(0_-)$$

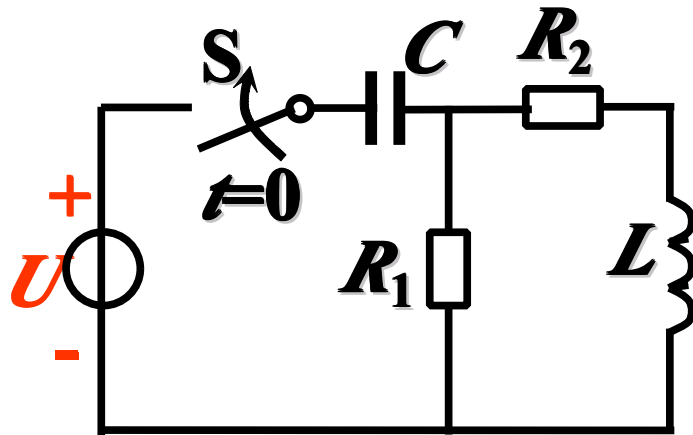
$$u_C(0_-) = 0, i_L(0_-) = 0$$

$$u_C(0_+) = u_C(0_-) = 0$$

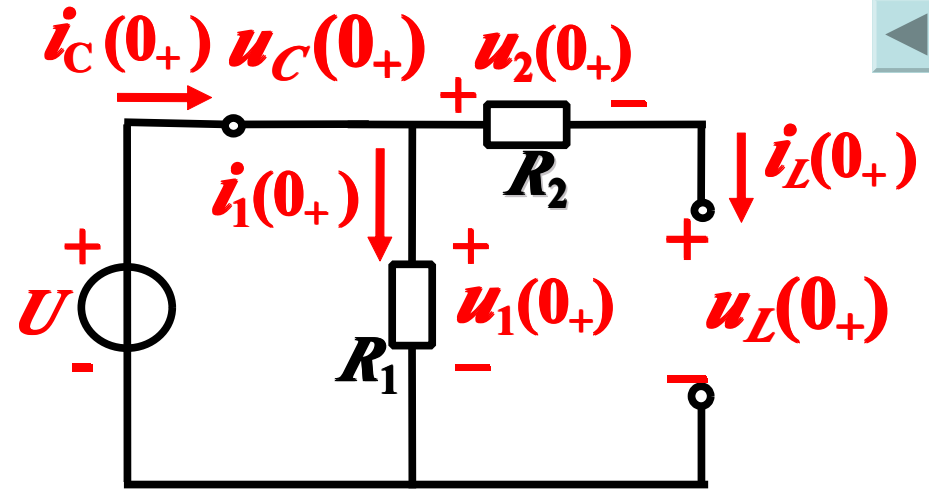
$$i_L(0_+) = i_L(0_-) = 0$$



1:



(a)



(b)  $t = 0+$

(2)  $t = 0_+$

$$u_C(0_-) = 0,$$

$$i_L(0_-) = 0,$$

$$i_C(0_+) = i_1(0_+) = \frac{U}{R}$$

$$u_L(0_+) = u_1(0_+) = U$$

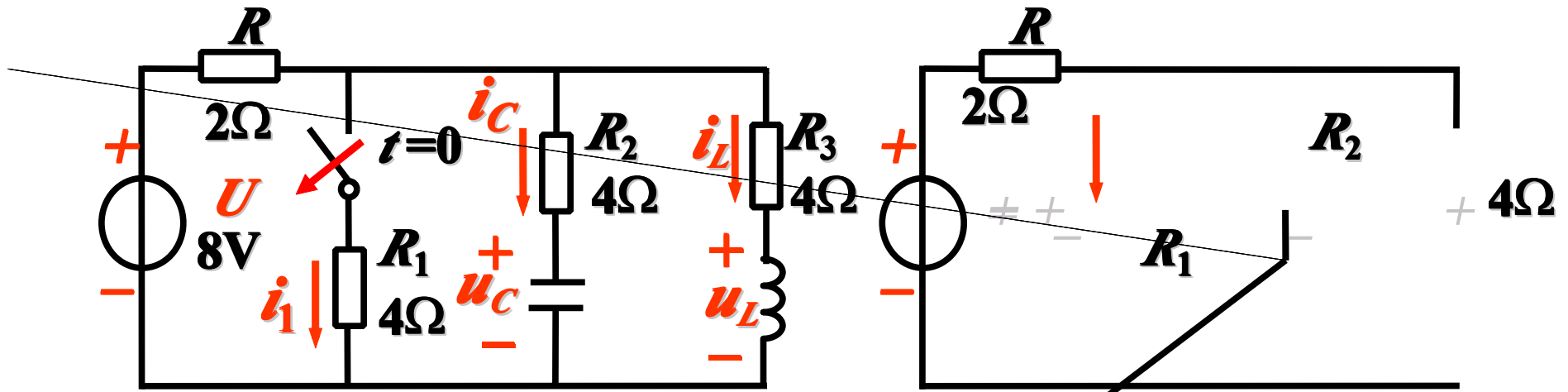
$$(i_C(0_-) = 0)$$

$$(u_L(0_-) = 0)$$

$i_C$   $u_L$

$$u_2(0_+) = 0$$

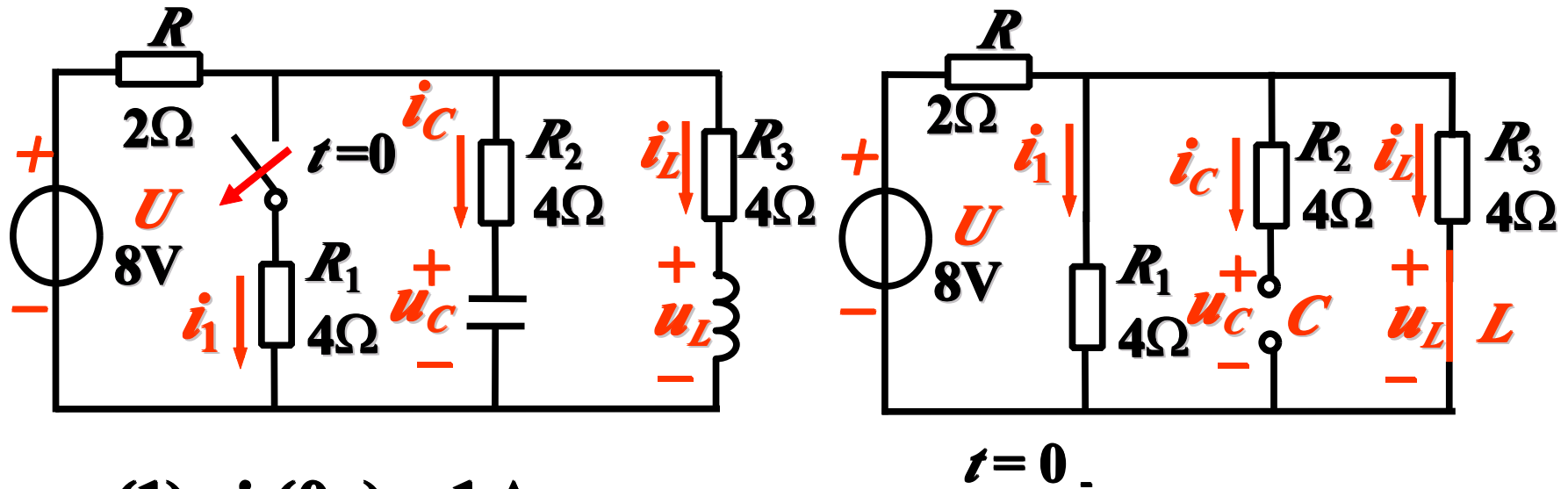
2



(1)  $t = 0_-$        $u_C(0_-)$        $i_L(0_-)$

$$i_L(0_-) = \frac{R_1}{R_1 + R_3} \times \frac{U}{R + \frac{R_1 R_3}{R_1 + R_3}} = \frac{4}{4 + 4} \times \frac{U}{2 + \frac{4 \times 4}{4 + 4}} = 1 \text{ A}$$

2



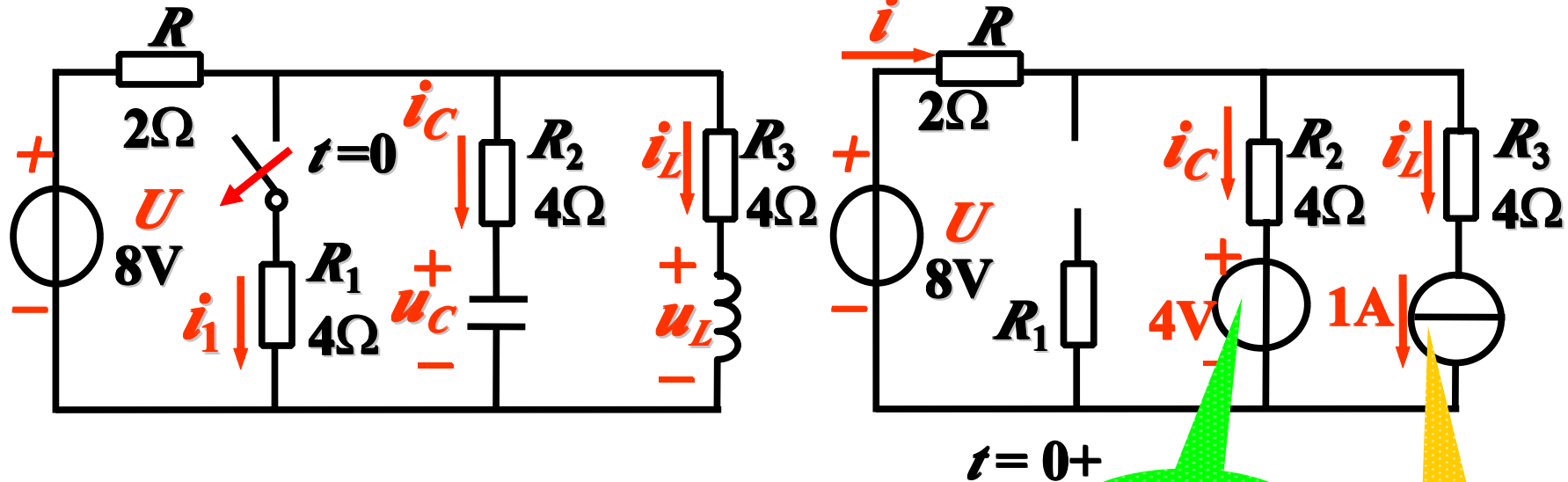
$$(1) \quad i_L(0_-) = 1 \text{ A}$$

$$u_C(0_-) = R_3 i_L(0_-) = 4 \times 1 = 4 \text{ V}$$

$$i_L(0_+) = i_L(0_-) = 1 \text{ A}$$

$$u_C(0_+) = u_C(0_-) = 4 \text{ V}$$

2



(2)  $t = 0_+$

$i_C(0_+)$

$u_L(0_+)$

$u_C(0_+)$

$i_L(0_+)$

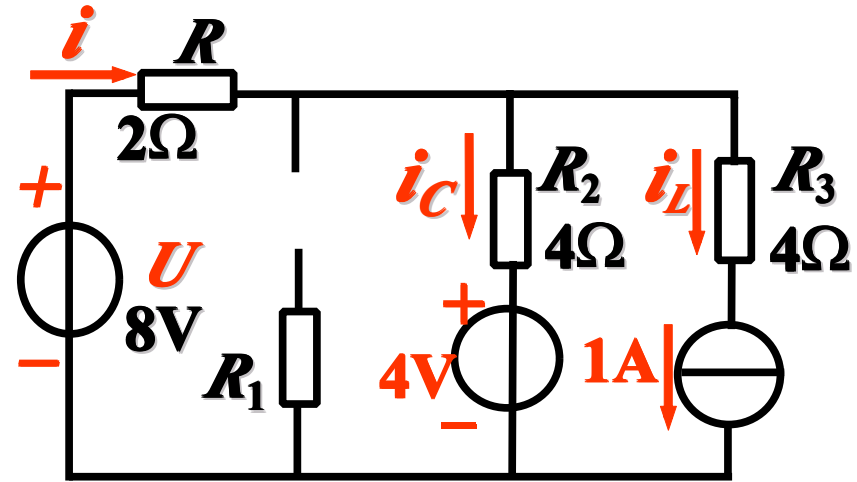
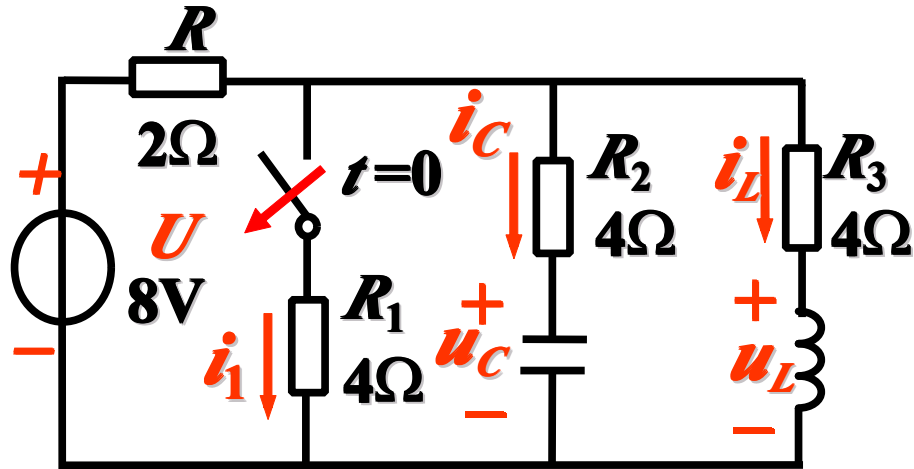
$$U = Ri(0_+) + R_2 i_C(0_+) + u_C(0_+)$$

$$i(0_+) = i_C(0_+) + i_L(0_+)$$

$$8 = 2i(0_+) + 4i_C(0_+) + 4$$

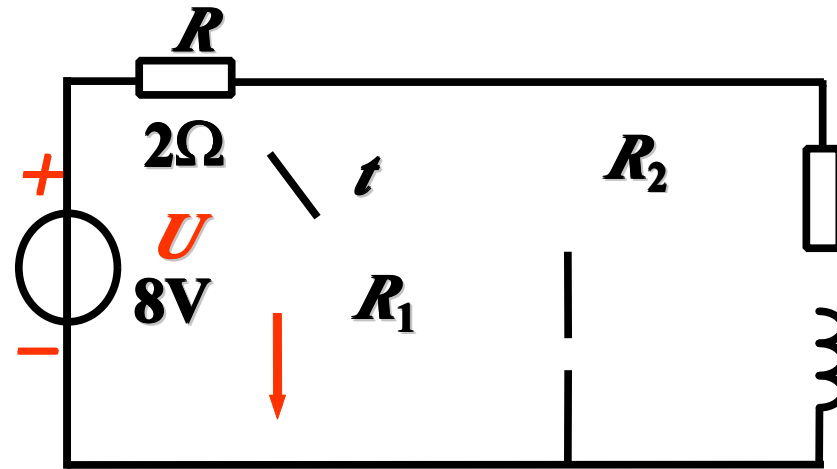
$$i(0_+) = i_C(0_+) + 1$$

2



$$i_C(0_+) = \frac{1}{3} \text{ A}$$

$$\begin{aligned} u_L(0_+) &= R_2 i_C(0_+) + u_C(0_+) - R_3 i_L(0_+) \\ &= 4 \times \frac{1}{3} + 4 - 4 \times 1 = 1\frac{1}{3} \text{ V} \end{aligned}$$



	$u_C / \text{V}$	$i_L / \text{A}$	$i_C / \text{A}$	$u_L / \text{V}$
$t=0_-$	4	1	0	0
$t=0_+$	4	1	$\frac{1}{3}$	$1\frac{1}{3}$

$u_C$   $i_L$

$i_C$   $u_L$





1.  $u_C$   $i_L$  ,

2. , , ( $t=0_+$   
)

3. ,  $u_C(0^-) \neq 0$   $i_L(0^-) \neq 0$  ( $t=0_+$   
)

$u_C(0_+)$ ;

$i_L(0_+)$

## 3.2



,

1.

:

(

)

(

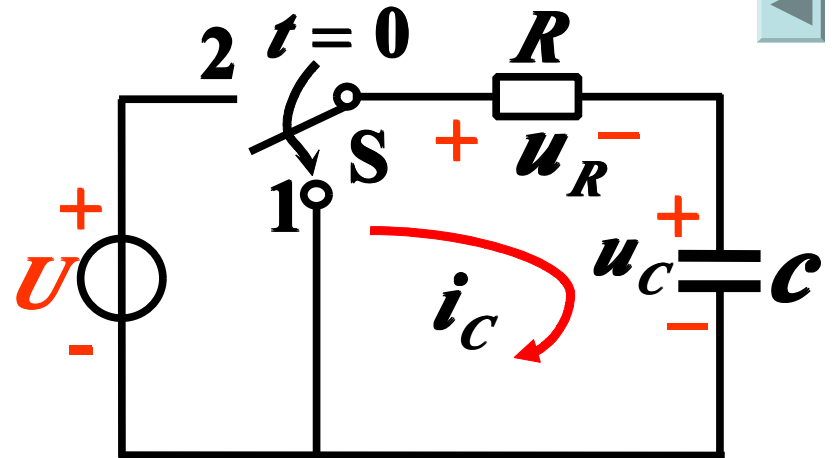
)

2.

{

### 3.2.1 RC

RC



$$u_C(0_-) = U$$

$$u_C(0_-) = U$$

$t=0$  S  $\rightarrow$  1,

C R

1.

$u_C$

$(t \geq 0)$

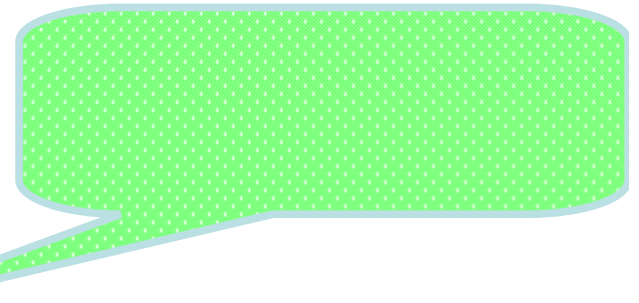
(1) KVL

$= i$

$$+ = 0$$

$$i = \frac{d}{d}$$

$$\frac{d}{d} + = 0$$



(2)

$$RC \frac{du_C}{dt} + u_C = 0 \quad : u_C = Ae^{pt}$$
$$+ 1 = 0 \quad \therefore = -\frac{1}{RC}$$

$$u_C = Ae^{-\frac{t}{RC}}$$

*A*

$$t = (0_+) \quad u_C(0_+) = U, \quad A = U$$

(3)

*u<sub>C</sub>*

$$u_C = U e^{-\frac{t}{RC}} = u_C(0_+) e^{-\frac{t}{\tau}} \quad t \geq 0$$

*u<sub>C</sub>*  
*RC*

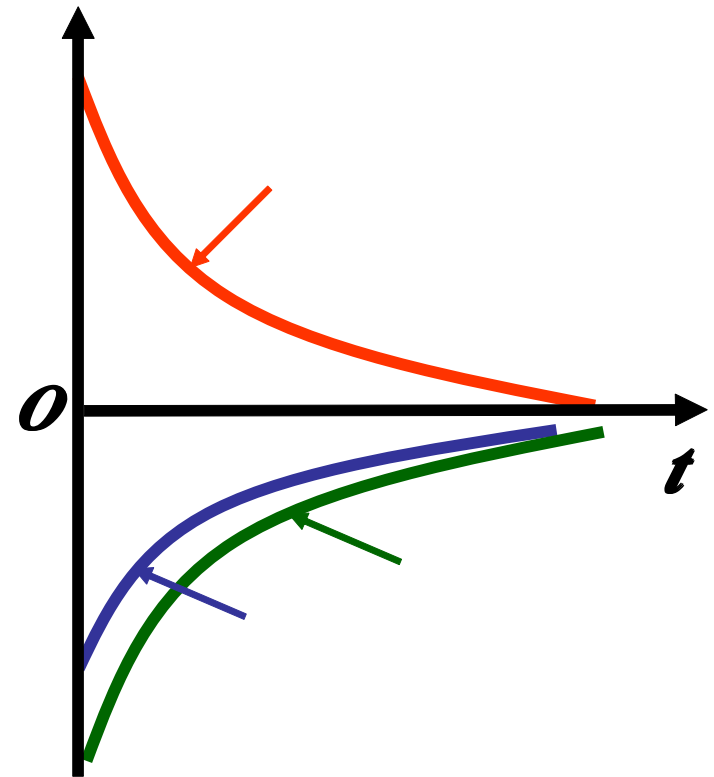


2.

$$u_C = U e^{-\frac{t}{RC}}$$

$$i_C = C \frac{du_C}{dt} = -\frac{U}{R} e^{-\frac{t}{RC}}$$

$$u_R = i_C R = -U e^{-\frac{t}{RC}}$$



3.



4.

:  $\tau = RC$  : S

(1)  $\Omega \frac{A \cdot s}{V} = S$

$\tau$

(2)

$$u_C(t) = U e^{-\frac{t}{RC}}$$

$$t = \tau \quad = e^{-1} = 36.8\%$$

$\therefore$

$\tau$

$u_C$

$U_0$

36.8%



(3)



$$t \rightarrow \infty \quad u_C \rightarrow 0$$

$$\underline{t = (3 \sim 5)\tau} \quad u_C \rightarrow 0$$

$$e^{-\frac{t}{\tau}}$$

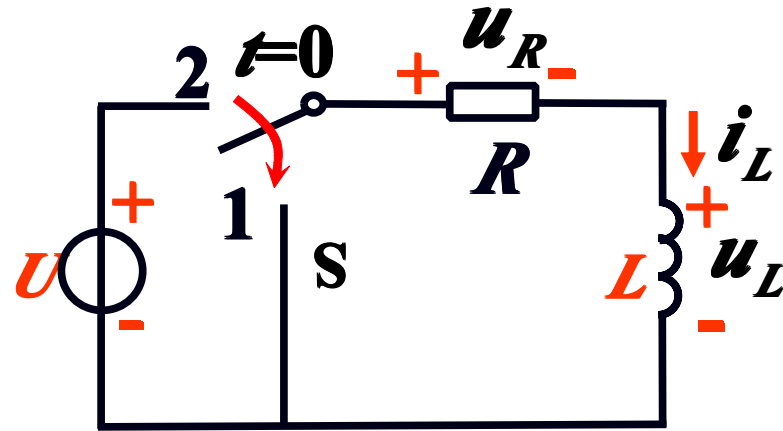
$t$	$\tau$	$2\tau$	$3\tau$	$4\tau$	$5\tau$	$6\tau$
$e^{-\frac{t}{\tau}}$	$e^{-1}$	$e^{-2}$	$e^{-3}$	$e^{-4}$	$e^{-5}$	$e^{-6}$
$u_C$	$0.368U$	$0.135U$	$0.050U$	$0.018U$	$0.007U$	$0.002U$

$$t=5\tau$$

$$u_C$$

### 3.2.2 *RL*

#### 1. *RL*



$$(0_-) = \text{---}$$

$t=0$

1,  $L$   $R$

(1)  $i_L$

1) KVL

$$= i$$

$$+ = 0$$

$$= \frac{d}{d}$$

$$-\frac{d}{d} + = 0$$





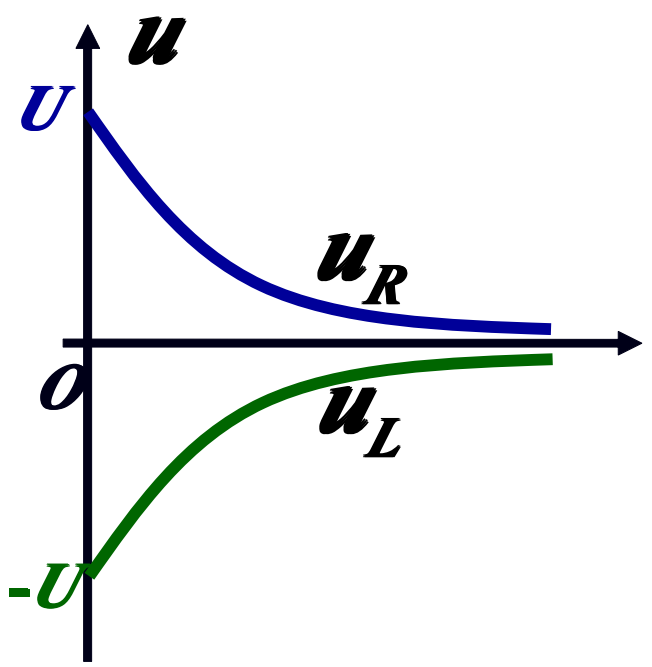
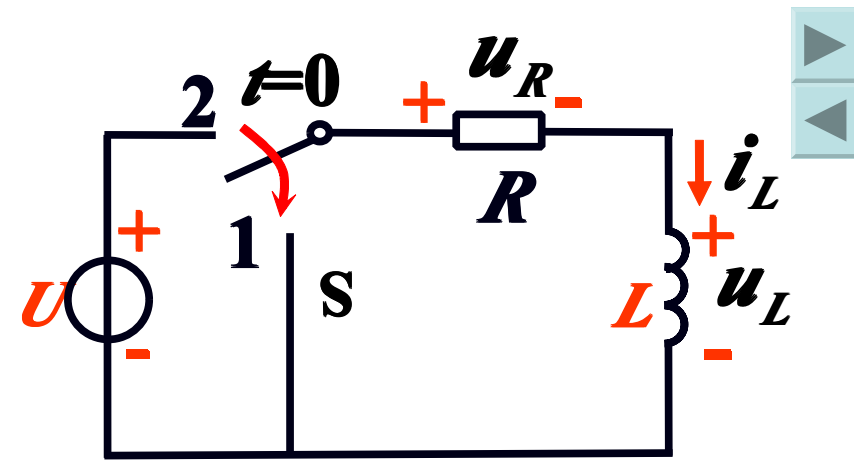


(2)

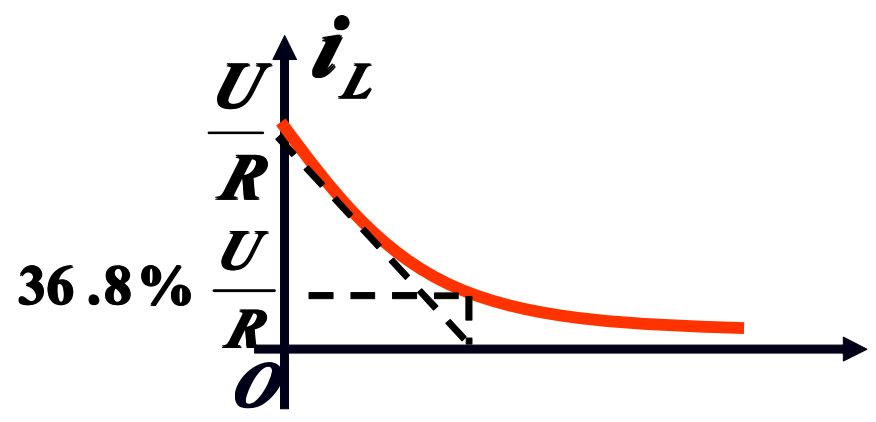
$$= -e^{-\frac{t}{\tau}}$$

$$= \frac{d}{dt} (-e^{-\frac{t}{\tau}}) = e^{-\frac{t}{\tau}}$$

$$= \frac{U}{R} e^{-\frac{t}{\tau}}$$



(3)



(4)

$$\tau = \frac{L}{R}$$

## 2. *RL*

(1)

1)

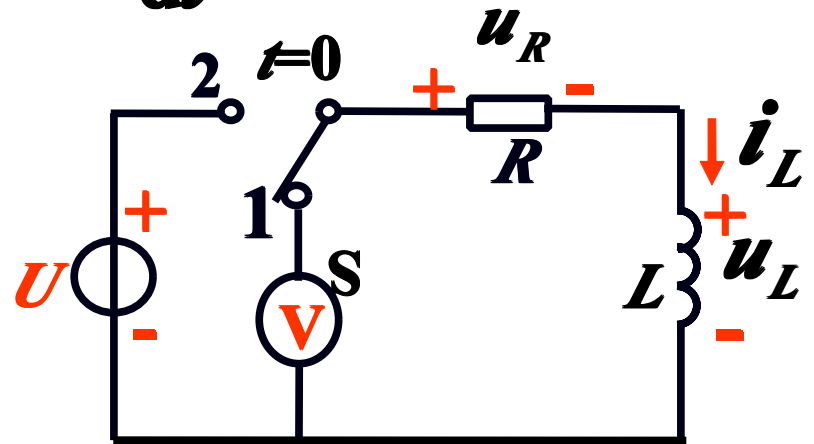
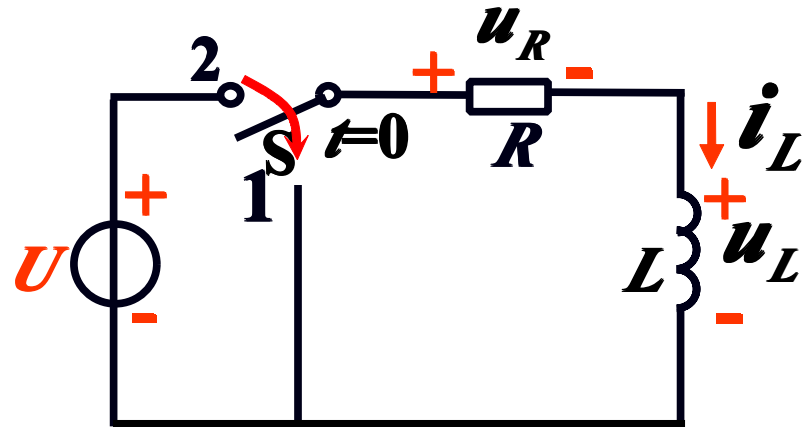
$$\therefore i_L(0_-) = \frac{U}{R}$$

$$i_L(0_+) = 0 \quad \therefore u_L = -e_L = L \frac{di}{dt} \rightarrow \infty$$

2)

$$\therefore i_L(0_+) = i_L(0_-) = \frac{U}{R}$$

$$V(0_+) = i_L(0_+) \times R = \frac{U}{R} \times R$$

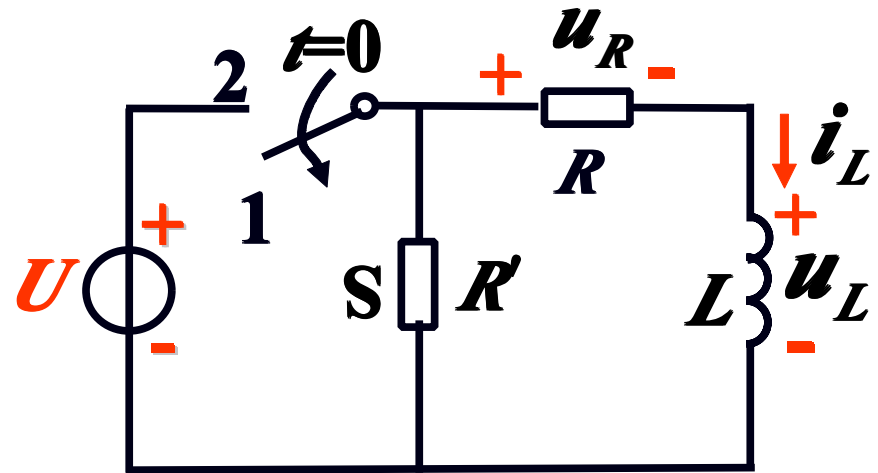




(2)

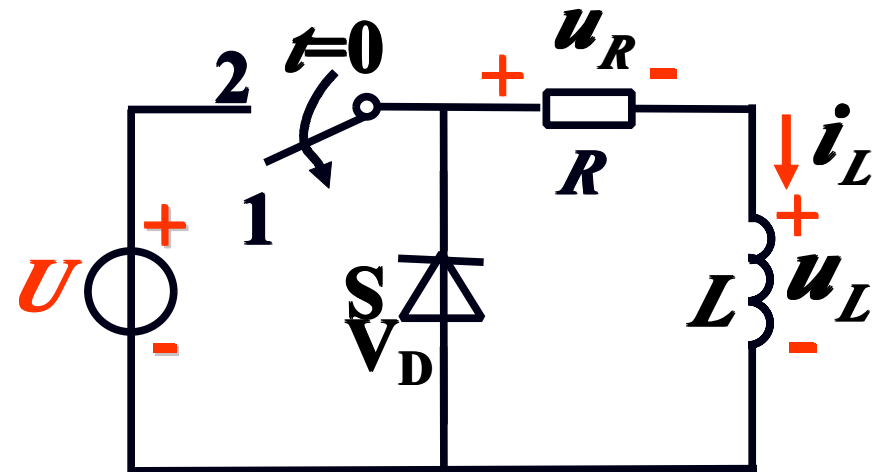
1)

$R'$



2)

$V_D$



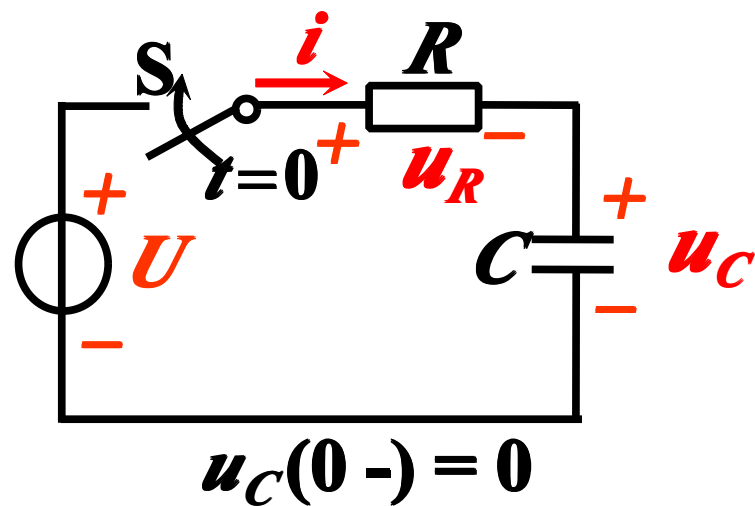
# 3.3

## 3.3.1 RC

RC

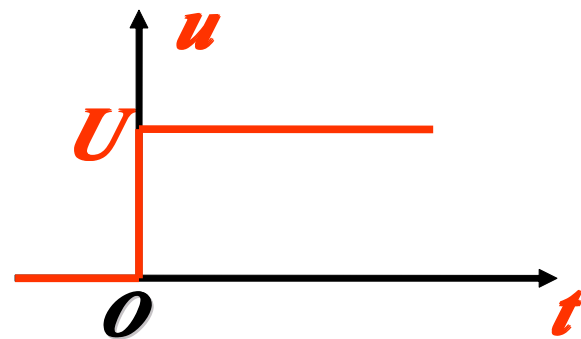
$t = 0$

S



,  
 $u$

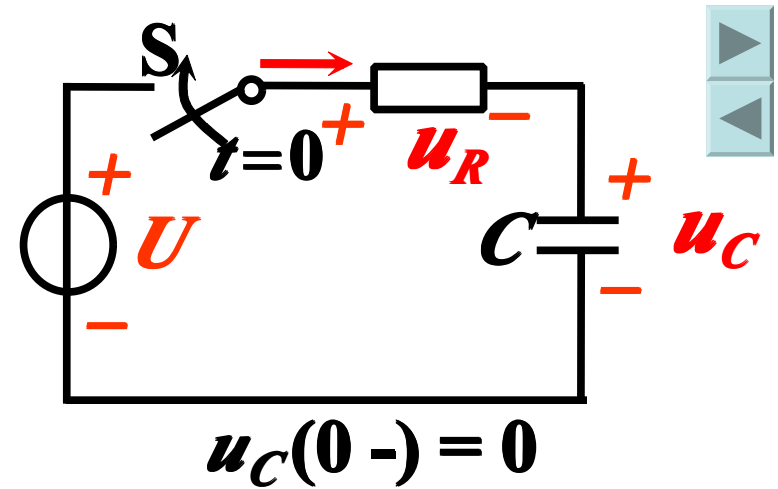
$$u = \begin{cases} 0 & t < 0 \\ U & t \geq 0 \end{cases}$$



1.  $u_C$

(1) KVL  $u_R + u_C = U$

$$RC \frac{du_C}{dt} + u_C = U$$



= +  
 $u_C(t) = u'_C + u''_C$

(2)

$$RC \frac{du_C}{dt} + u_C = U$$

$$u'_C = K, \quad U = RC \frac{dK}{dt} + K$$

$$K = U, \quad u'_C = U$$

$$\therefore u_C = u'_C + u''_C = U + Ae^{-\frac{t}{RC}}$$

$$u'_C$$

$$u'_C(t) = u_C(\infty) = U$$

$$RC \frac{du_C}{dt} + u_C = 0$$

$$u''_C = Ae^{pt} = Ae^{-\frac{t}{RC}}$$

$$u_C = u'_C + u''_C = U + Ae^{-\frac{t}{\tau}} \quad \tau = RC$$

$A$

$t=0_+$

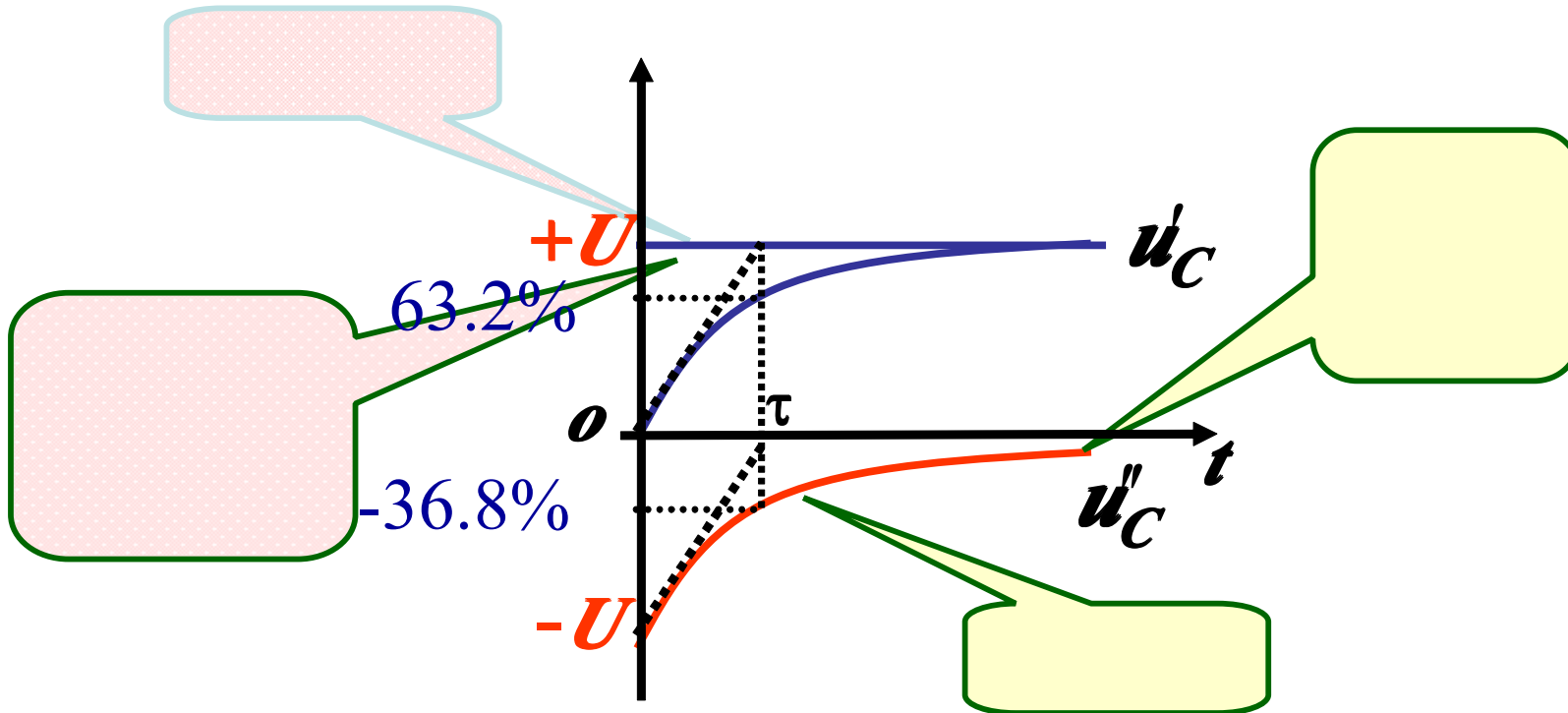
$$u_C(0_+) = 0$$

$$A = -U$$

(3)

$u_C$

$$u_C = U - Ue^{-\frac{t}{RC}}$$



$$u_C = U(1 - e^{-\frac{t}{RC}}) = U(1 - e^{-\frac{t}{\tau}}) \quad (t \geq 0)$$







2.  $i_C$

$$i_C = C \frac{du_C}{dt} = \frac{U}{R} e^{-\frac{t}{\tau}} \quad t \geq 0$$

$t = 0$

3.  $u_C$   $i_C$

$$u_C = U(1 - e^{-\frac{t}{RC}})$$

4.  $\tau$

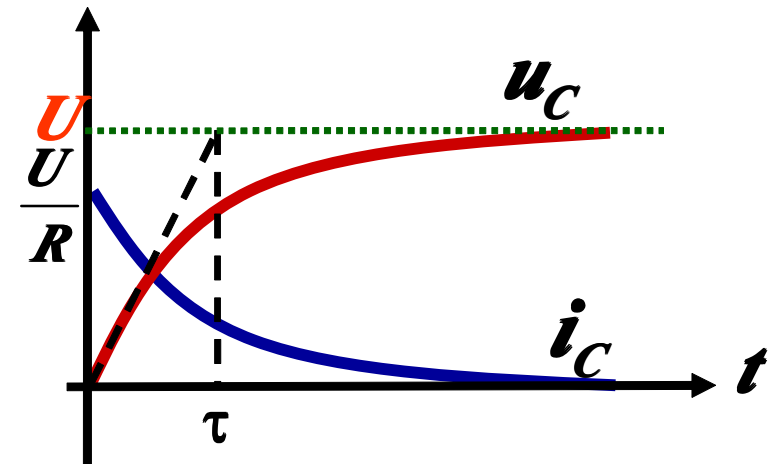
$t = \tau$

$$u_C(\tau) = U(1 - e^{-1}) = 63.2\%U$$

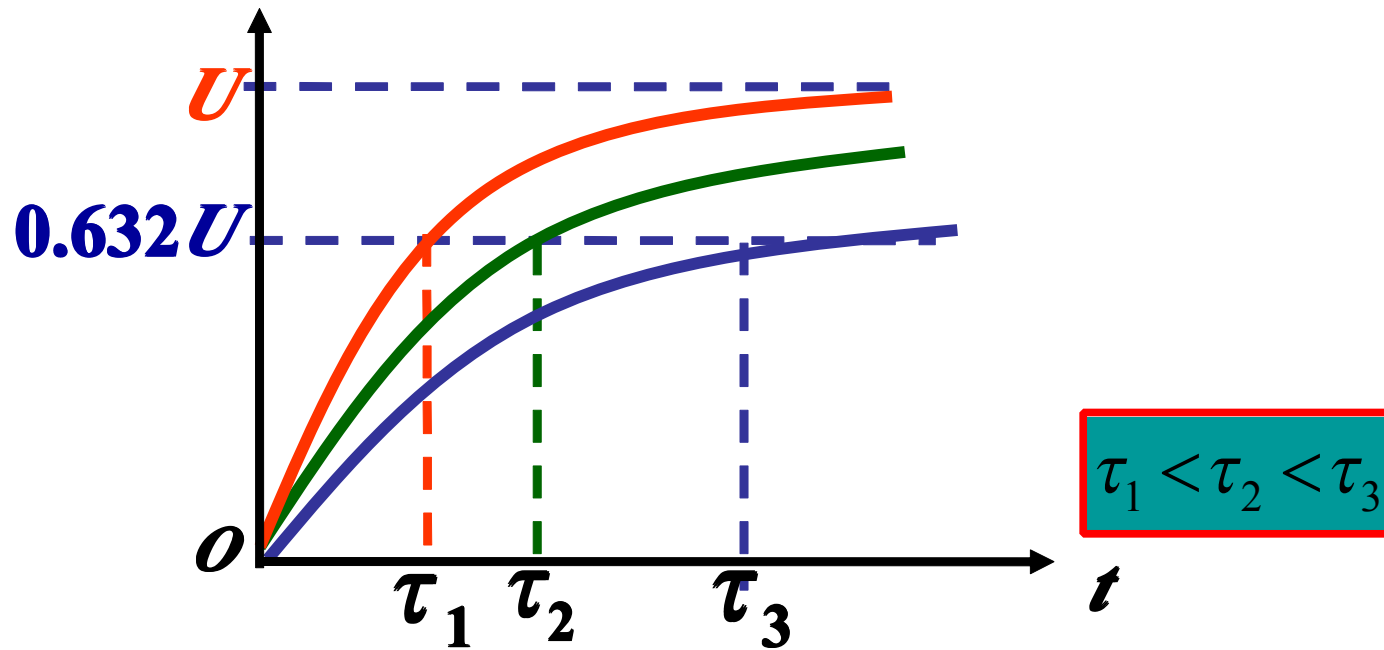
$\tau$

63.2%

$u_C$



	$0$	$\tau$	$2\tau$	$3\tau$	$4\tau$	$5\tau$	$6\tau$
$u_C$	$0$	$0.632U$	$0.865U$	$0.950U$	$0.982U$	$0.993U$	$0.998U$



$\tau$

$u_C$

$t = 5\tau$  ,

$u_C$

### 3.3.2 *RL*

#### 1. $i_L$

(1) KVL

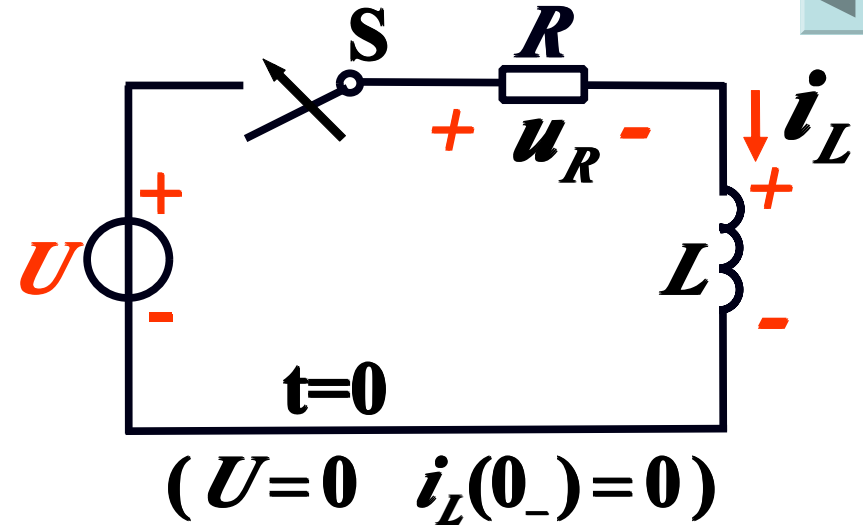
$$-\frac{d}{d} + = -$$

$$= +$$

$$() = ' + ''$$

(2)

$$() = (\infty) = -$$





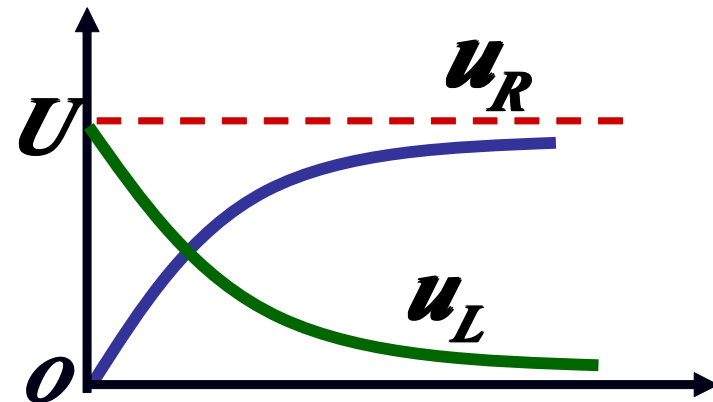
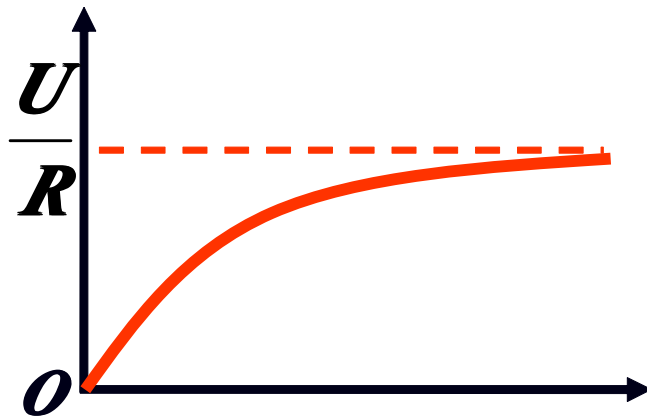
$$i_L = \frac{U}{R} (1 - e^{-\frac{R}{L}t})$$

$$u_L = L \frac{di}{dt} = U e^{-\frac{t}{\tau}} = U e^{-\frac{R}{L}t}$$

$$u_R = i_L R = U (1 - e^{-\frac{R}{L}t})$$



2.  $i_L$   $u_L$   $u_R$



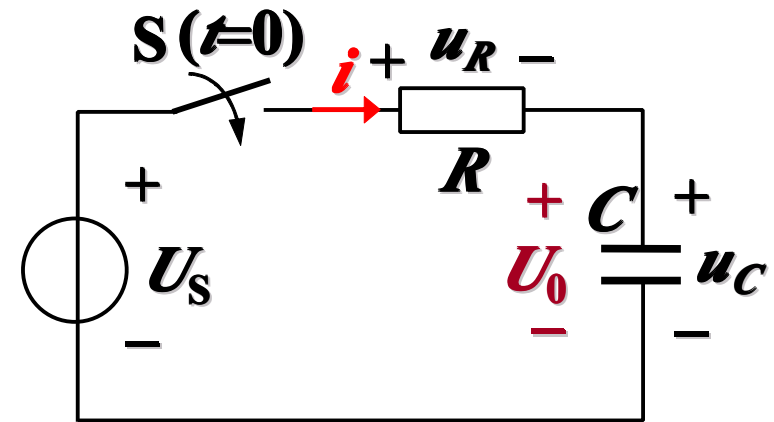
# 3.4



1.

$$RC \frac{du_C}{dt} + u_C = U_S$$

$$u_C(0_+) = u_C(0_-) = U_0$$



2.

$$u_C = U_S + (U_0 - U_S) e^{-\frac{t}{\tau}}$$

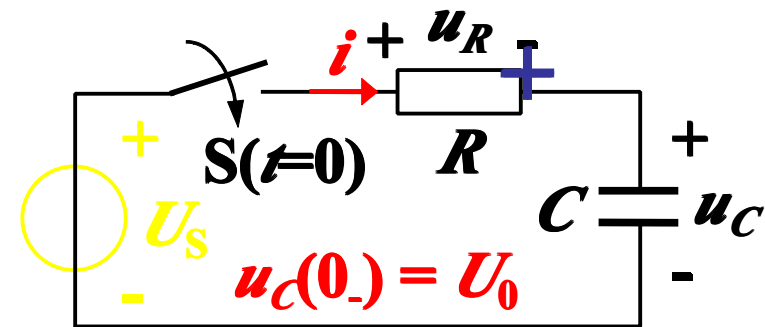
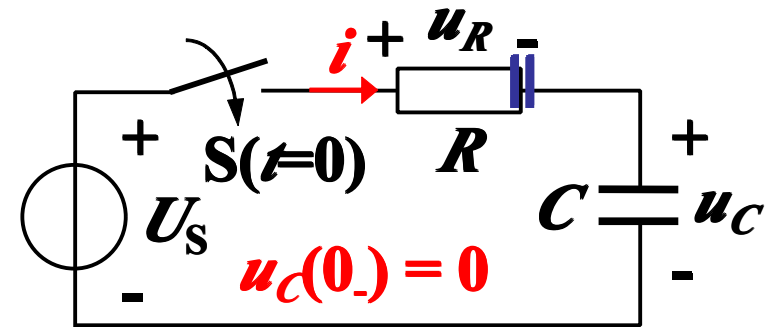
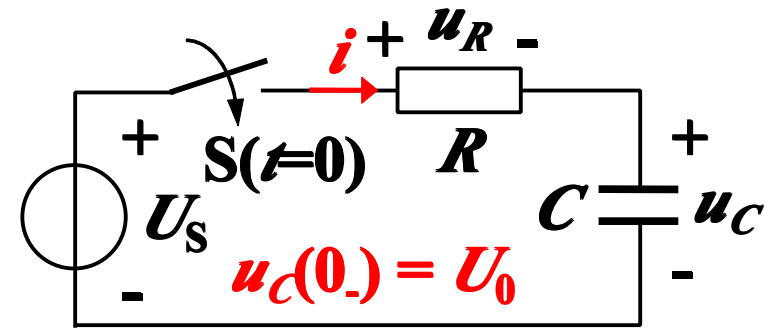
(1)

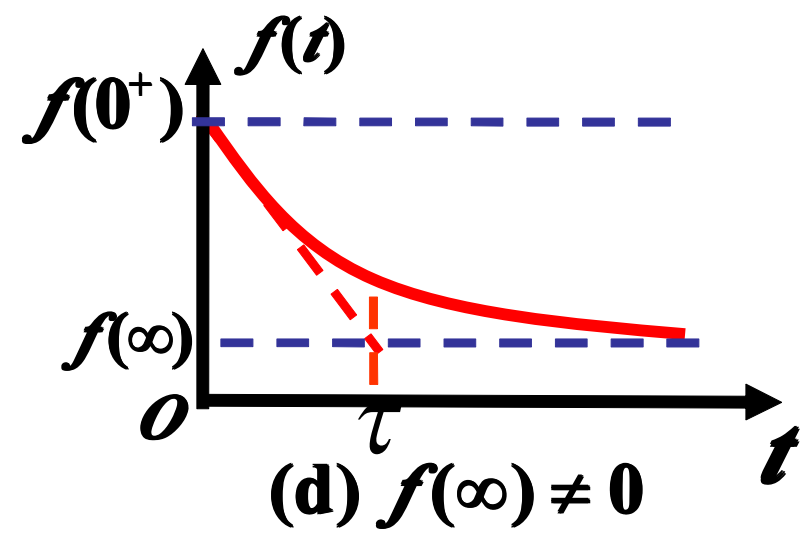
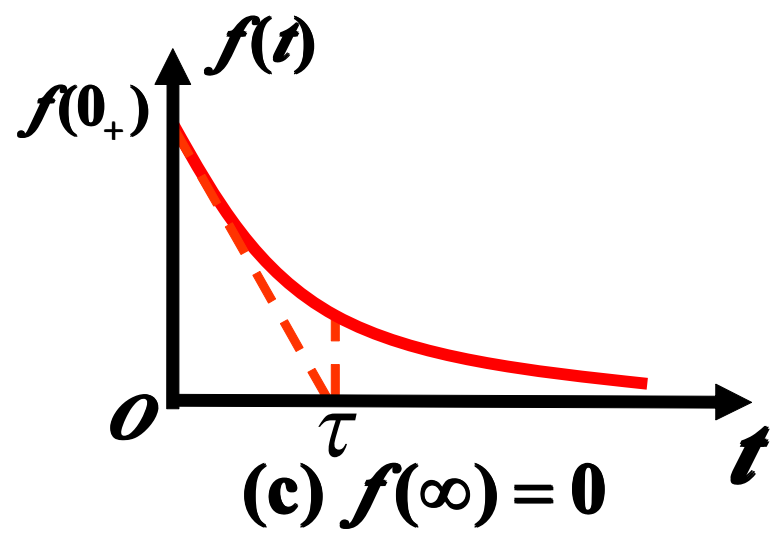
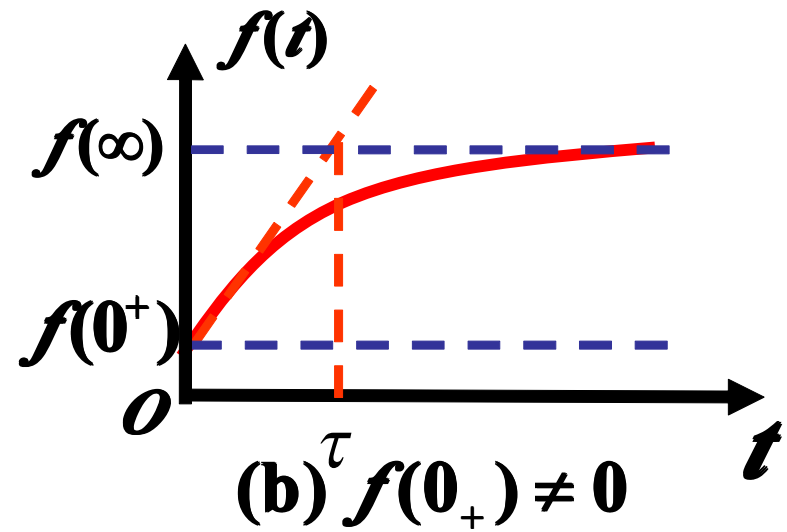
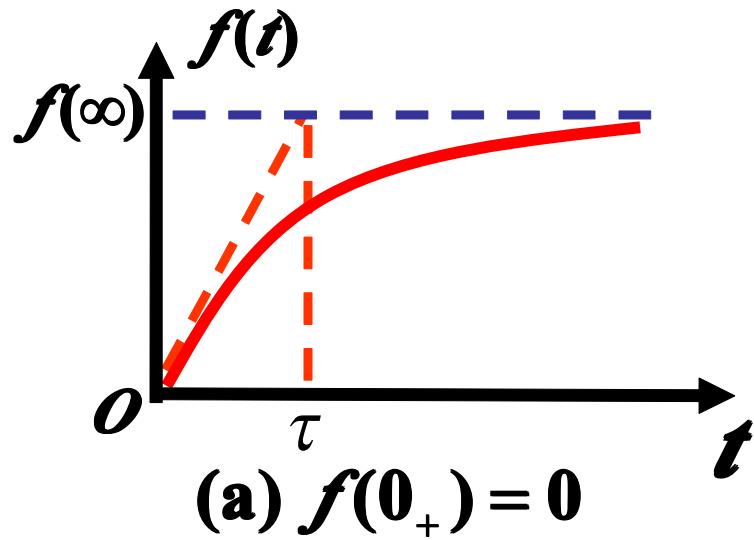
( )  
( )

$$u_C = U_S + (U_0 - U_S) e^{-\frac{t}{\tau}}$$

(2)

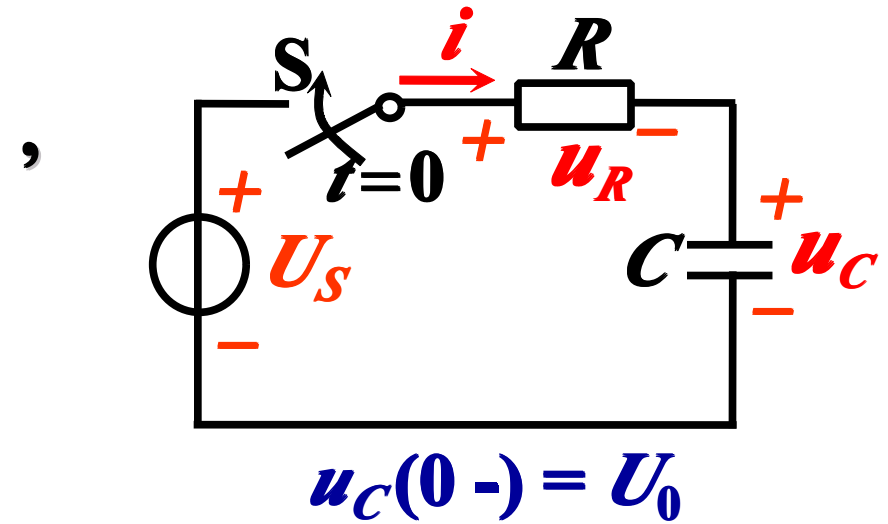
$$u_C = U_S (1 - e^{-\frac{t}{\tau}}) + U_0 e^{-\frac{t}{\tau}}$$







# 3.5



$$= \underline{\quad} + (\underline{u_C(0^-)} - \underline{\quad}) e^{-\frac{t}{\tau}}$$

$$(\infty) = \underline{\quad}$$

$$(0_+) = \underline{u_C(0_-)} = \underline{U_0}$$

$$\underline{u_C} = \underline{u_C(\infty)} + [\underline{u_C(0_+)} - \underline{u_C(\infty)}] e^{-\frac{t}{RC}}$$



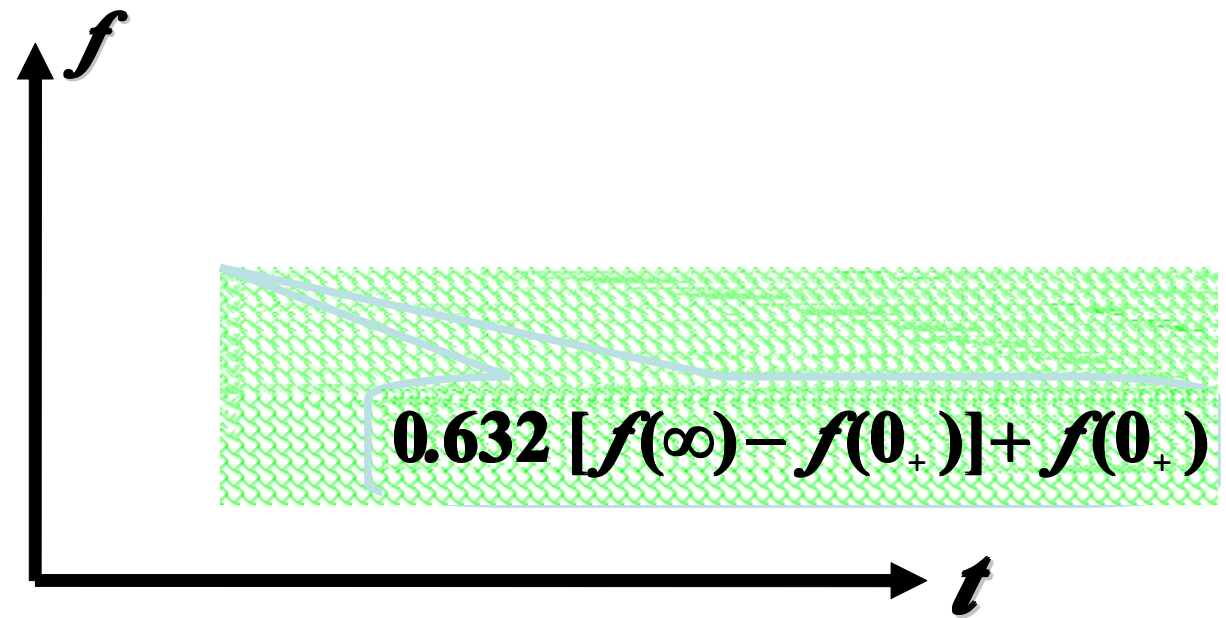
$$f(t) = f(\infty) + [f(0_+) - f(\infty)] e^{-t/\tau}$$

,  $f(t)$

$$\left\{ \begin{array}{l} f(0_+) \text{ ---} \\ f(\infty) \text{ ---} \\ \tau \text{ ---} \end{array} \right.$$

$\tau$

( )







**(2)**  $f(0_+)$

1)  $t=0_-$   $u_C(0_-)$   $i_L(0_-)$

2)  $\left\{ \begin{array}{l} u_C(0_+) = u_C(0_-) \\ i_L(0_+) = i_L(0_-) \end{array} \right.$

3)  $t=0_+$   $u(0_+)$   $i(0_+)$

**(3)**  $\tau$

$RC$

$$\tau = R_0 C$$

$RL$

$$\tau = \frac{L}{R_0}$$

1)

$$R_0 = R;$$

2)

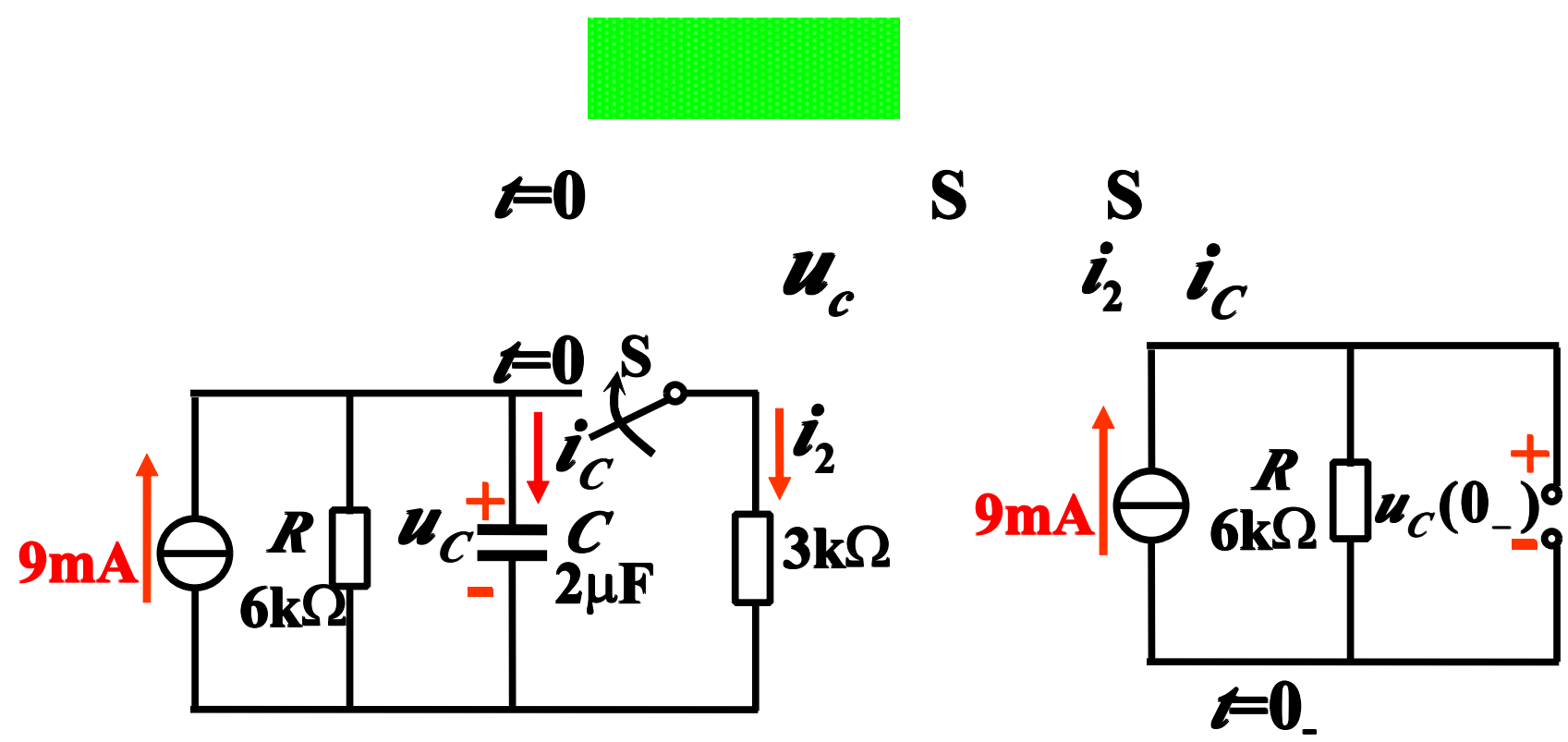
$$R_0$$



  $R_0$



$$R_0 = (R_1 // R_2) + R_3$$



$$u_c = u_c(\infty) + [u_c(0_+) - u_c(\infty)] e^{-\frac{t}{\tau}}$$

(1)

$$u_c(0_+) = u_c(0_-) = 9 \times 10^{-3} \times 6 \times 10^3 = 54 \text{ V}$$
$$u_c(0_+) = u_c(0_-) = 54 \text{ V}$$

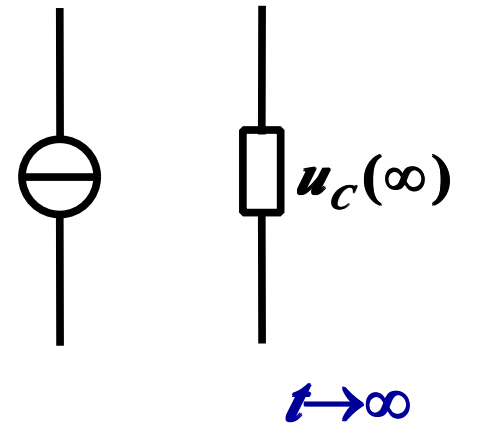


(2)  $u_c(\infty)$

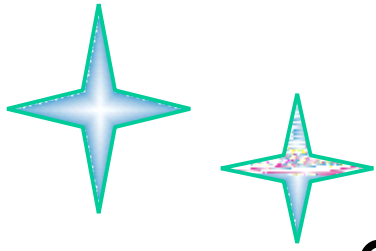
$$u_c(\infty) = 9 \times 10^{-3} \times \frac{6 \times 3}{6 + 3} \times 10^3$$
$$= 18 \text{ V}$$

(3)  $\tau$

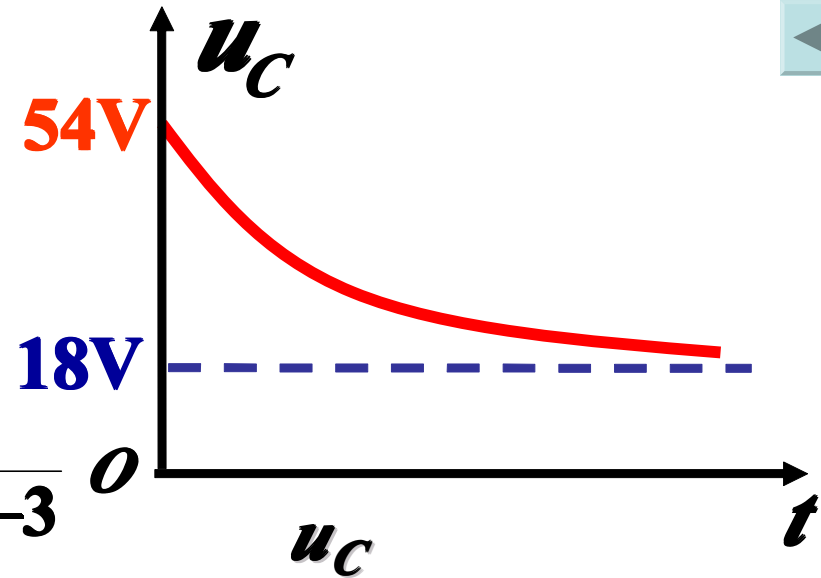
$$\tau = R_0 C$$
$$= \frac{6 \times 3}{6 + 3} \times 10^3 \times 2 \times 10^{-6}$$
$$= 4 \times 10^{-3} \text{ s}$$







$$\begin{cases} u_C(0_+) = 54 \text{ V} \\ u_C(\infty) = 18 \text{ V} \\ \tau = 4 \times 10^{-3} \text{ s} \end{cases}$$

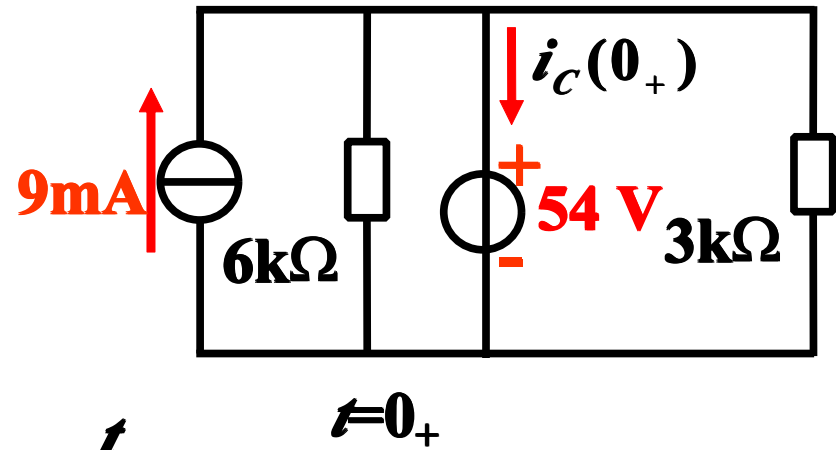
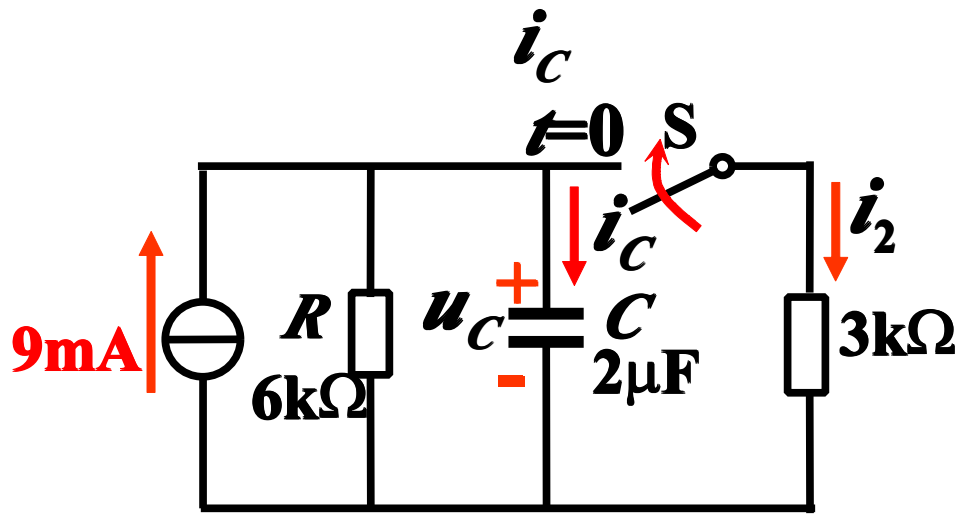


$$\begin{aligned} \therefore u_C &= 18 + (54 - 18)e^{-\frac{t}{4 \times 10^{-3}}} \\ &= 18 + 36e^{-250t} \text{ V} \end{aligned}$$

$u_C$

$$\begin{aligned} i_C &= C \frac{du_C}{dt} = 2 \times 10^{-6} \times 36 \times (-250)e^{-250t} \\ &= -0.018e^{-250t} \text{ A} \end{aligned}$$





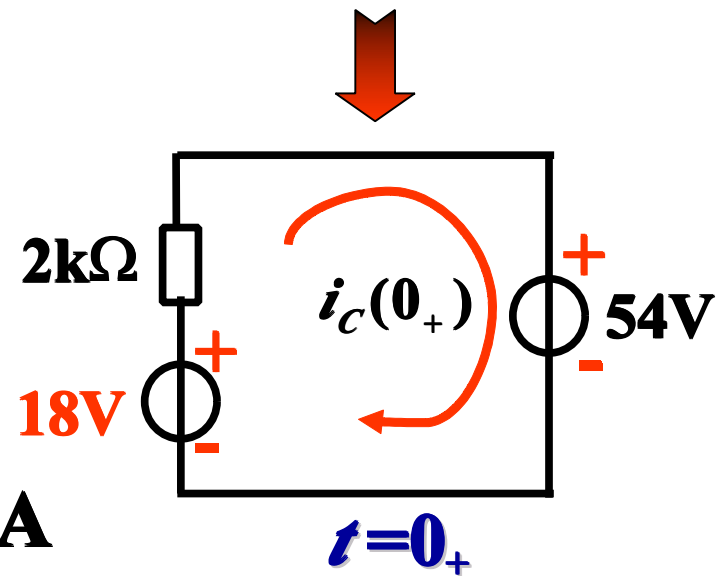
$$i_c = i_c(\infty) + [i_c(0_+) - i_c(\infty)] e^{-\frac{t}{\tau}}$$

$$i_c(0_+) = \frac{18 - 54}{2 \times 10^3} = -18 \text{ mA}$$

$$i_c(\infty) = 0$$

$$i_c(t) = -18 e^{-250t} \text{ mA}$$

$$i_2(t) = \frac{u_C(t)}{3 \times 10^3} = 6 + 12 e^{-250t} \text{ mA}$$



2

S



$t=0$  S  
 $i_1$   $i_2$

$t=0$

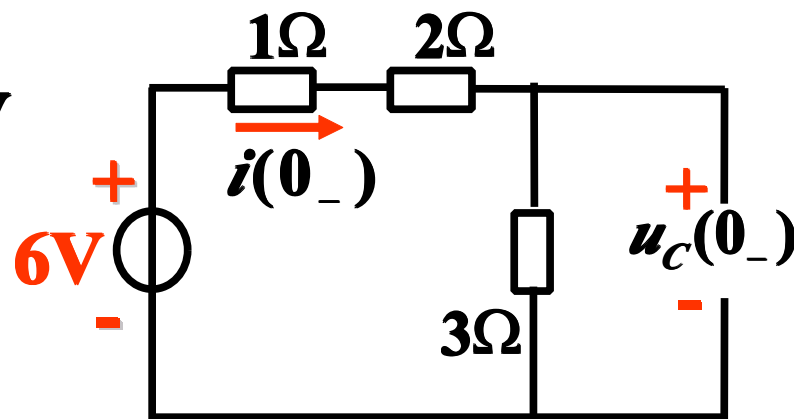
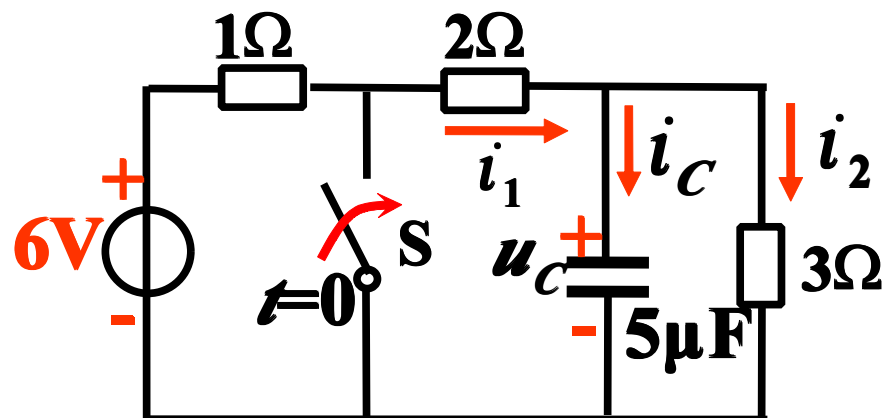
$u_C$   $i_C$

$u_C(0_+)$

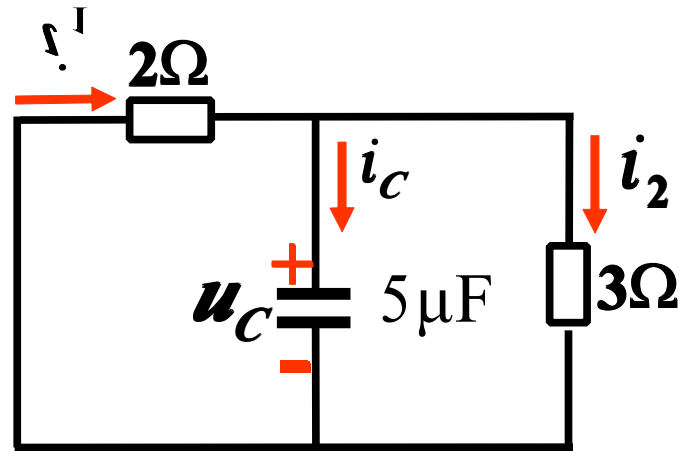
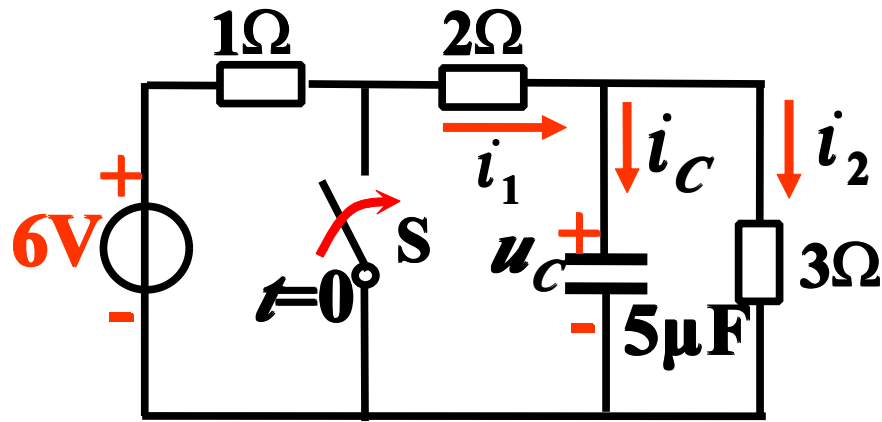
$t=0-$

$$u_C(0_-) = \frac{6}{1+2+3} \times 3 = 3 \text{ V}$$

$$u_C(0_+) = u_C(0_-) = 3 \text{ V}$$



$t=0_-$

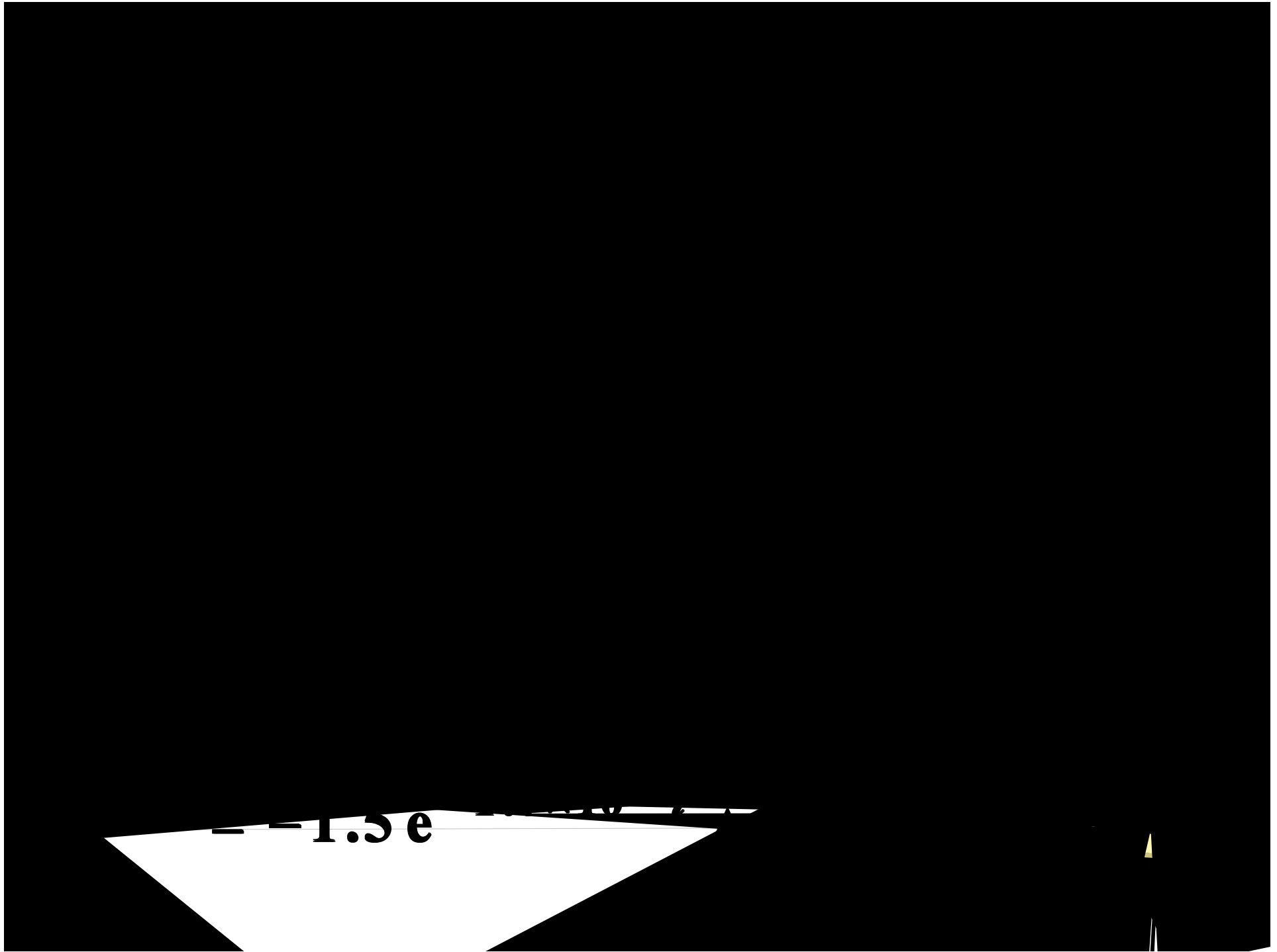


$$u_C(\infty) \quad u_C(\infty) = 0$$

$$\tau$$

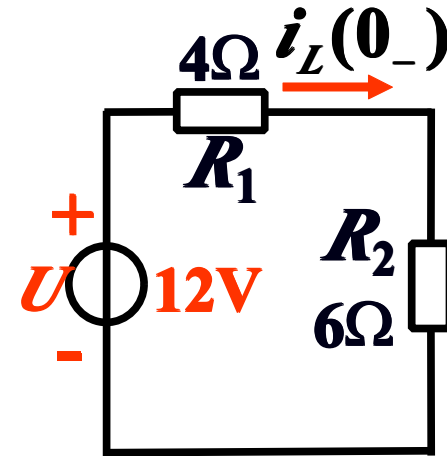
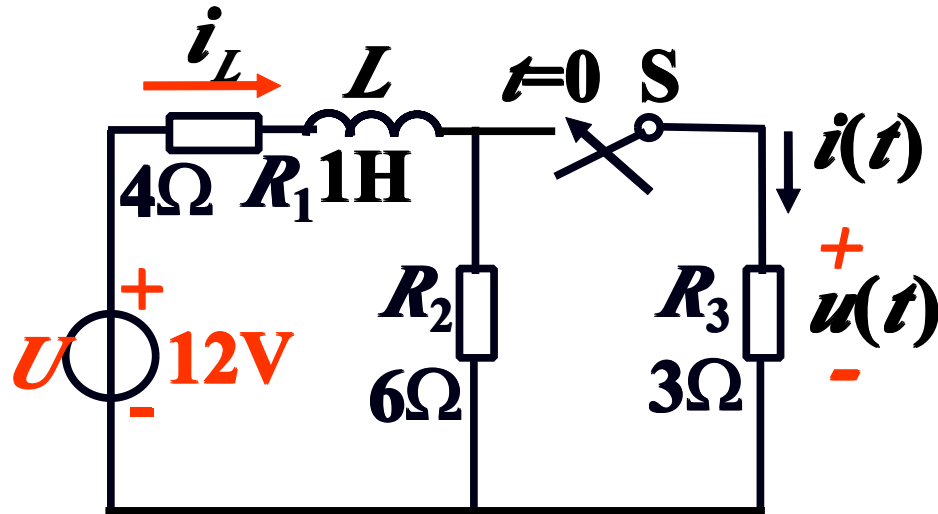
$$\tau = R_0 C = \frac{2 \times 3}{2 + 3} \times 5 \times 10^{-6} = 6 \times 10^{-6} \text{ s}$$

$$\begin{aligned} \therefore u_C(t) &= u_C(\infty) + [u_C(0_+) - u_C(\infty)] U e^{-\frac{t}{\tau}} \\ &= 0 + 3e^{-\frac{10^6}{6}t} = 3e^{-1.7 \times 10^5 t} \text{ V} \end{aligned}$$



3

$t=0$



$t=0_-$

1.  $i_L$  ( )

$$i_L = i_L(\infty) + [i_L(0_+) - i_L(\infty)] e^{-\frac{t}{\tau}}$$

$$i_L(0_+) = i_L(0_-) = \frac{U}{R_1 + R_2} = \frac{12}{4 + 6} = 1.2 \text{ A}$$

$$i_L(\infty) = \frac{U}{R_1 + \frac{R_2 \times R_3}{R_2 + R_3}}$$

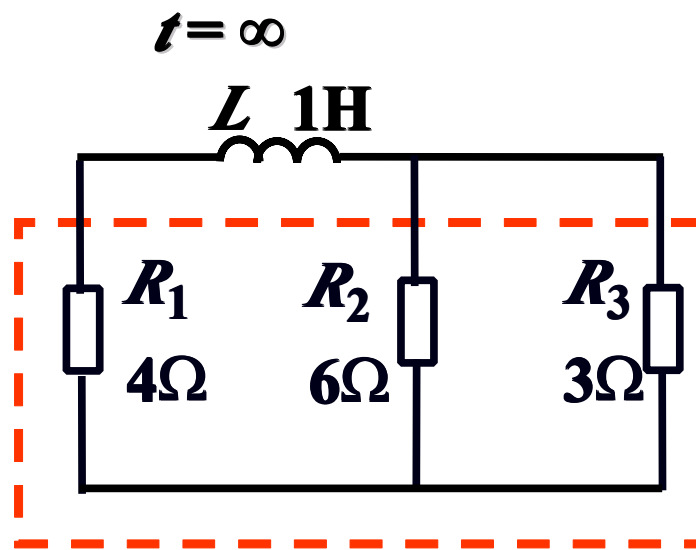
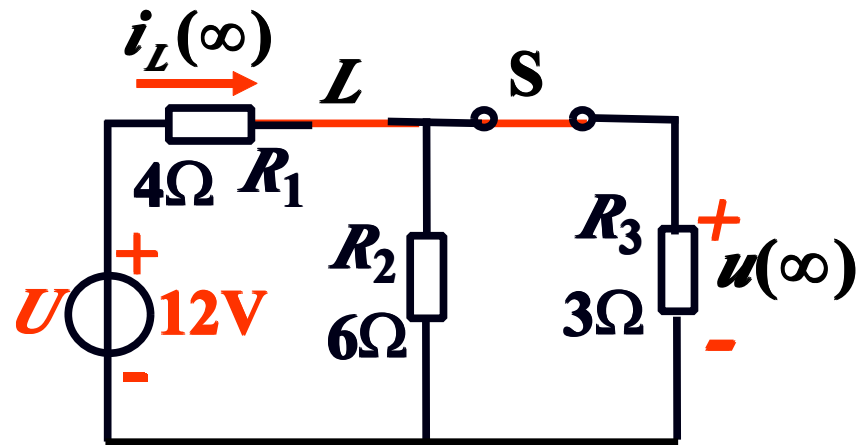
$$= 2 \text{ A}$$

$$\tau = \frac{L}{R_0}$$

$$= \frac{L}{R_1 + \frac{R_2 \times R_3}{R_2 + R_3}}$$

$$= \frac{1}{6} \text{ s}$$

$$\therefore i_L = 2 + (1.2 - 2)e^{-6t} = 2 - 0.8e^{-6t} \quad (t \geq 0)$$



## 2. $u(t)$

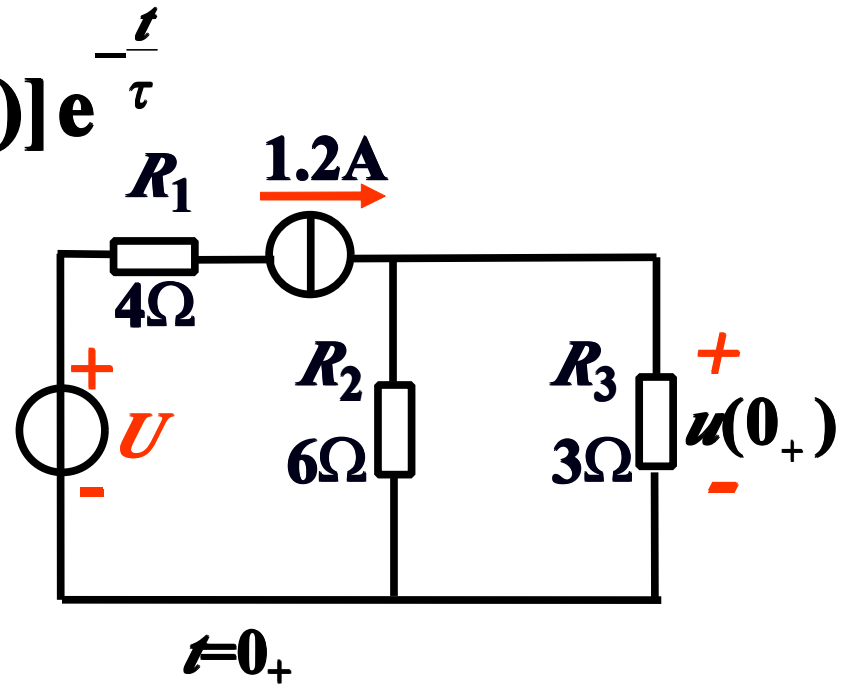
$$u = iR_3 = \frac{R_2}{R_2 + R_3} \times i_L \times R_3$$

$$u = \frac{6 \times 3}{6 + 3} (2 - 0.8e^{-6t}) = 4 - 1.6e^{-6t} \text{ V } (t \geq 0)$$

$u$

$$u = u(\infty) + [u(0_+) - u(\infty)] e^{-\frac{t}{\tau}}$$

$$\begin{aligned} u(0_+) &= \frac{6}{6+3} \times 1.2 \times R_3 \\ &= \frac{2}{3} \times 1.2 \times 3 = 2.4 \text{ V} \end{aligned}$$







$$\begin{aligned}u(\infty) &= \frac{R_2}{R_2 + R_3} i_L(\infty) \times R_3 \\ &= \frac{6}{9} \times 2 \times 3 = 4 \text{ V} \\ \tau &= \frac{L}{R_0} = \frac{1}{6} \text{ s} \\ u &= 4 + (2.4 - 4)e^{-6t} \\ &= 4 - 1.6e^{-6t} \text{ V } (t \geq 0)\end{aligned}$$



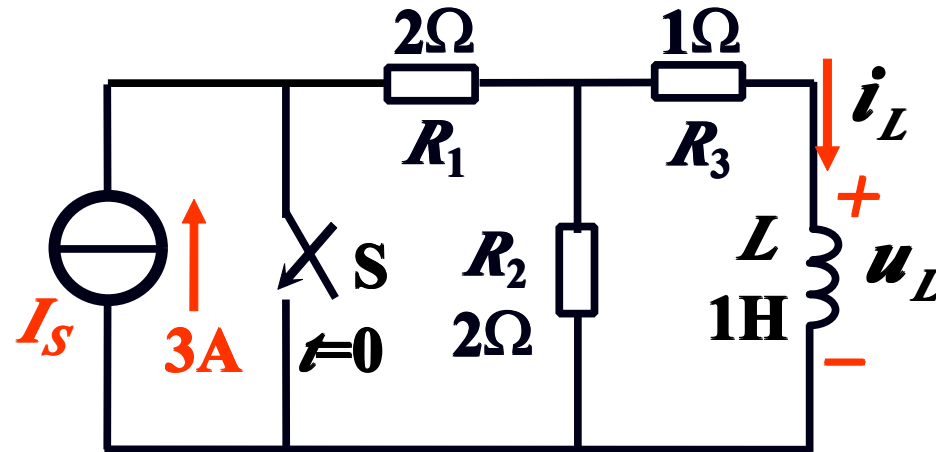
4:

S  $t=0$

:

$i_L$

$u_L$



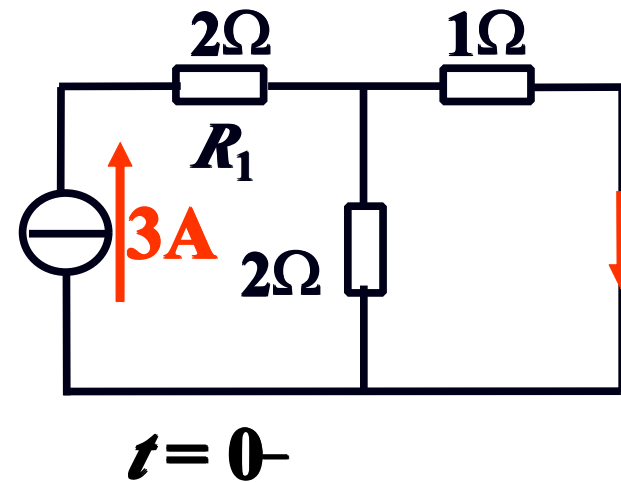
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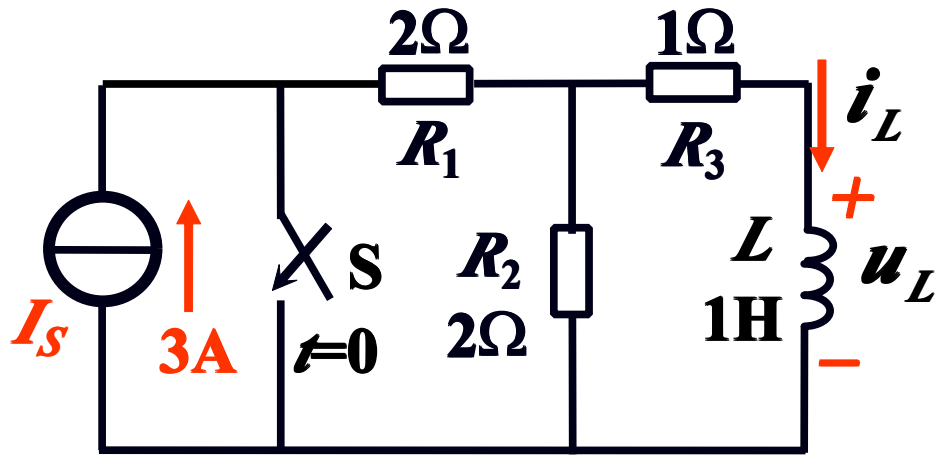
(1)  $u_L(0_+)$ ,  $i_L(0_+)$

$t=0^-$

$$i_L(0_-) = \frac{2}{1+2} \times 3 = 2 \text{ A}$$

$$i_L(0_+) = i_L(0_-) = 2 \text{ A}$$





$$i_L(0_+) = i_L(0_-) = 2A$$

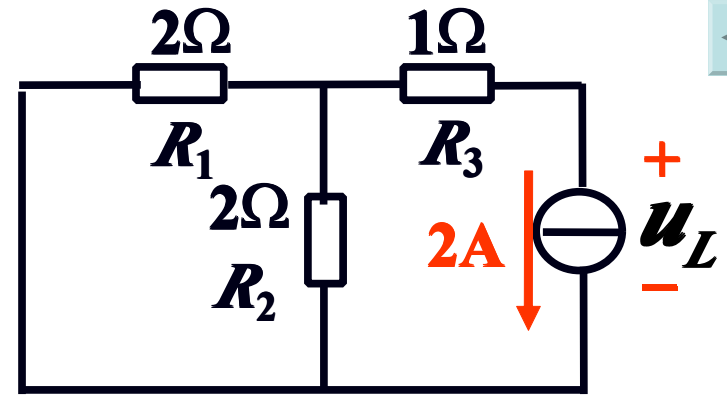
$$t = 0_+$$

$$u_L(0_+) = -i_L(0_+) \times \left( \frac{2 \times 2}{2 + 2} + 1 \right) = -4V$$

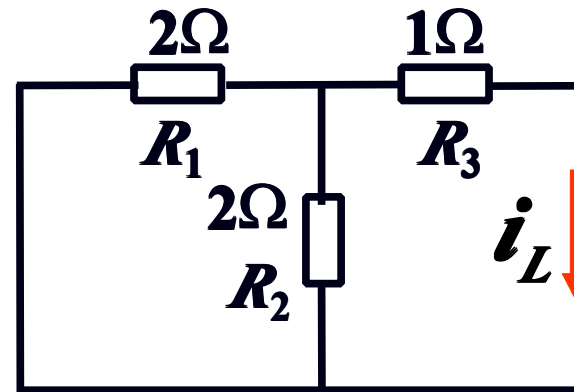
$$(2) \quad i_L(\infty) \quad u_L(\infty)$$

$$t = \infty$$

$$i_L(\infty) = 0V \quad u_L(\infty) = 0V$$



$$t = 0_+$$



$$t = \infty$$



(3)

$$R_0 = R_1 // R_2 + R_3$$
$$\tau = \frac{L}{R_0} = \frac{1}{2} = 0.5 \text{ s}$$
$$i_L = 0 + (2 - 0) e^{-2t}$$
$$= 2 e^{-2t} \text{ A}$$
$$u_L = 0 + (-4 - 0) e^{-2t}$$
$$= -4 e^{-2t} \text{ V}$$

