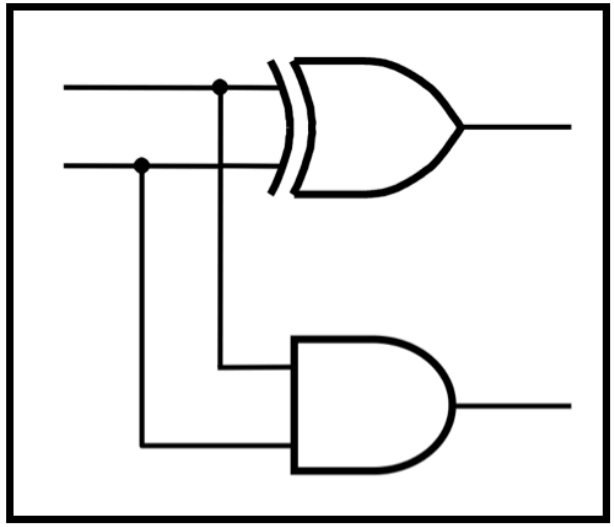


CprE 281: Digital Logic

Instructor: Alexander Stoytchev

http://www.ece.iastate.edu/~alexs/classes/

T Flip-Flops
&
JK Flip-Flops

CprE 281: Digital Logic
Iowa State University, Ames, IA

Administrative Stuff

- **Homework 8 is due on Monday Oct 25 @ 4pm.**

- **The second midterm exam is next week (Friday Oct 29).**

Administrative Stuff

- **Midterm Exam #2**
- **When: Friday October 29 @ 4:20pm.**
- **Where: This room**
- **What: Chapters 1, 2, 3, 4 and 5**
- **The exam will be closed book but open notes (you can bring up to 3 pages of handwritten notes).**

Midterm 2: Format

- **The exam will be out of 130 points**
- **You need 95 points to get an A for this exam**
- **It will be great if you can score more than 100 points.**
  - **but you can't roll over your extra points ☹**

Midterm 2: Topics

- K-maps for 2, 3, and 4 variables
- Binary Numbers and Hexadecimal Numbers
- 1's complement and 2's complement representation
- Addition and subtraction of binary numbers
- Circuits for adders and fast adders, delay calculation

- Single and Double precision IEEE floating point formats
- Converting a real number to the IEEE format
- Converting a floating point number to base 10

- Multiplexers (circuits and function)
- Synthesis of logic functions using multiplexers
- Shannon's Expansion Theorem

Midterm 2: Topics

- Decoders (circuits and function)
- Demultiplexers
- Encoders (binary and priority)
- Code Converters and Comparison Circuits

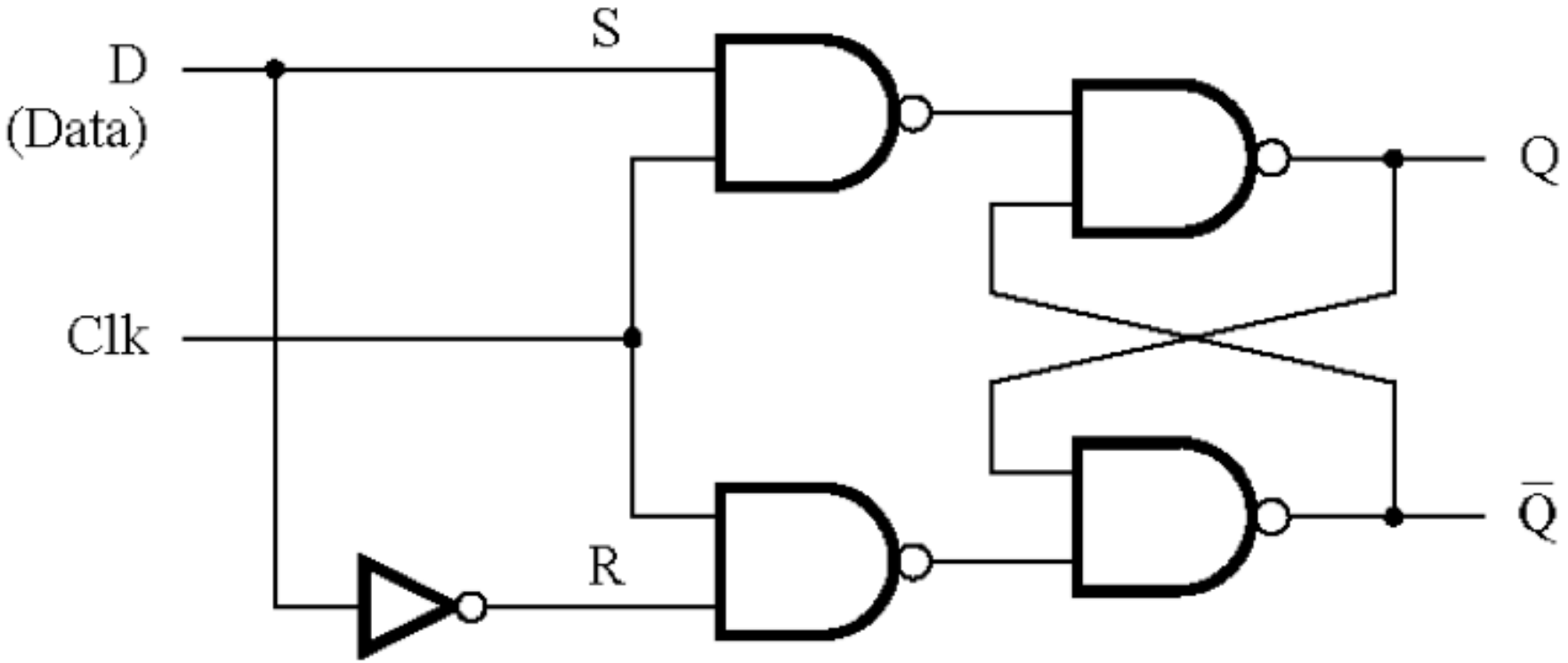
- Synthesis of logic circuits using adders, multiplexers, encoders, decoders, and basic logic gates
- Synthesis of logic circuits given constraints on the available building blocks that you can use

- Latches (circuits, behavior, timing diagrams)
- Flip-Flops (circuits, behavior, timing diagrams)
- Registers and Register Files
- Counters

Quick Review

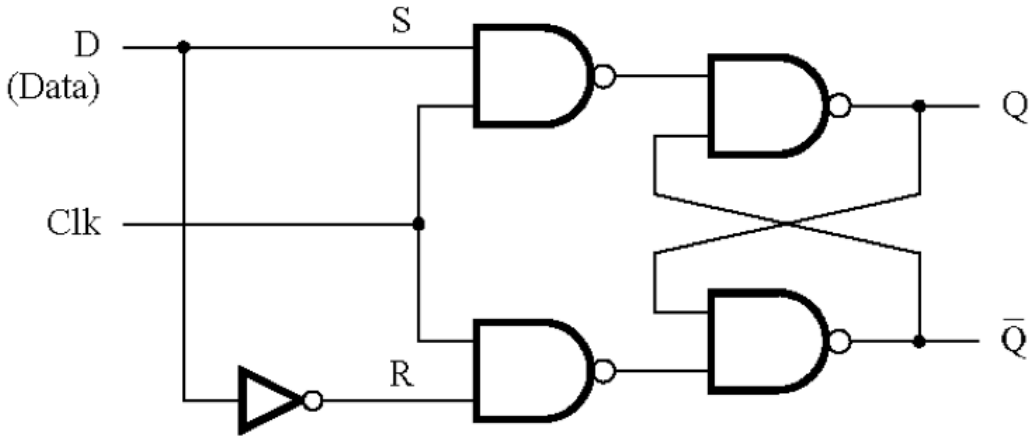
Gated D Latch

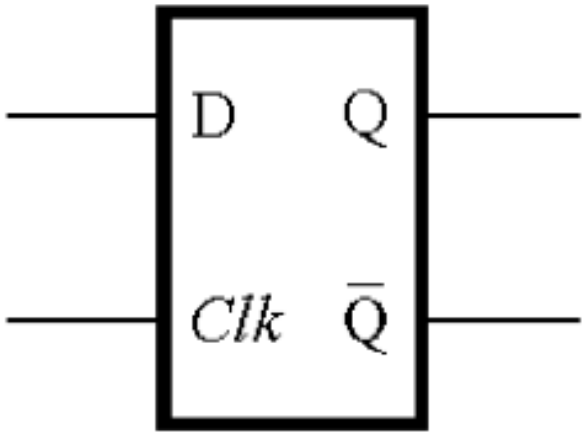
Circuit Diagram for the Gated D Latch



[Figure 5.7a from the textbook]

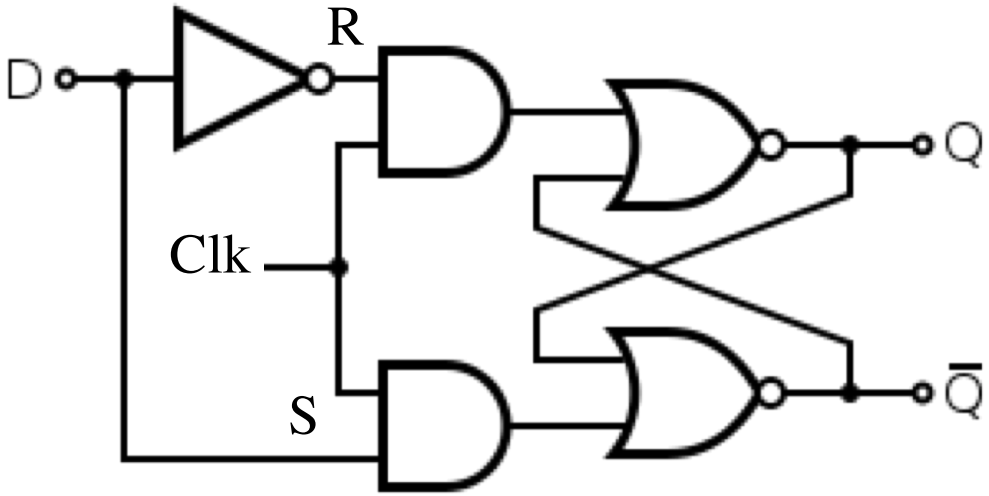
Circuit Diagram and Graphical Symbol for the Gated D Latch





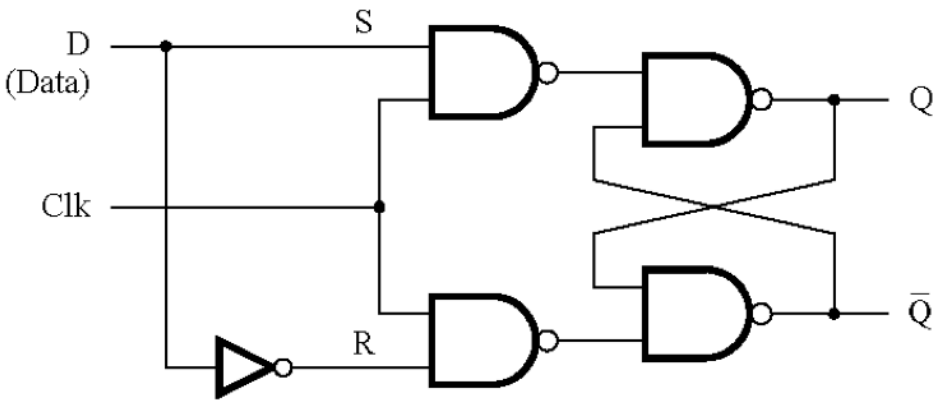
[Figure 5.7a,c from the textbook]

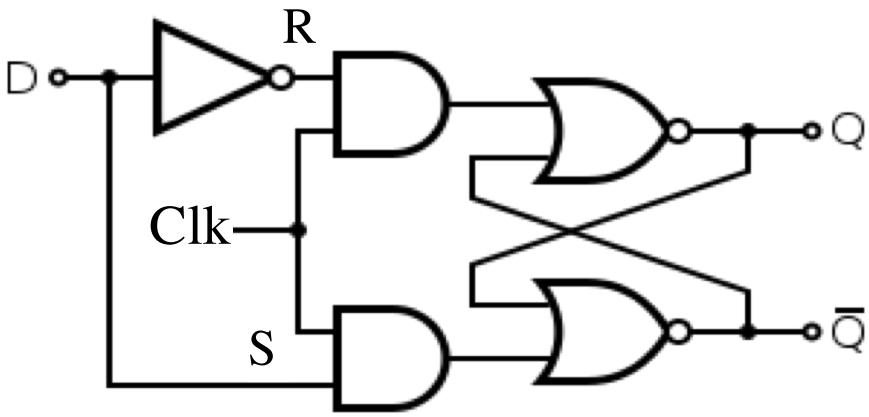
Circuit Diagram for the Gated D Latch (with the latch implemented using NORs)



[https://en.wikibooks.org/wiki/Digital_Circuits/Latches]

Circuit Diagram for the Gated D Latch (with the latch implemented using NORs)

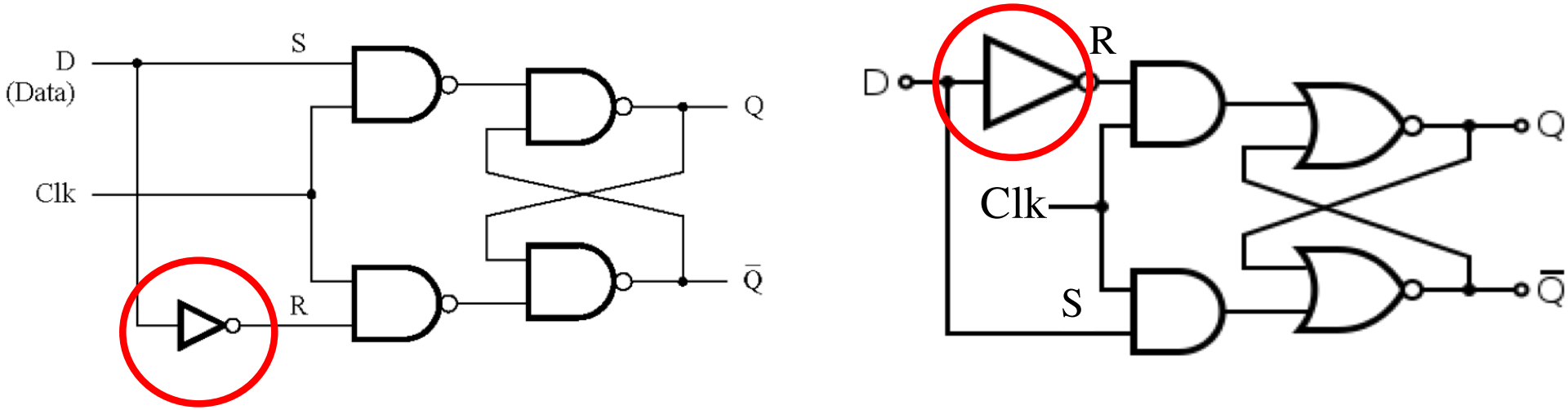




[Figure 5.7a from the textbook]

[https://en.wikibooks.org/wiki/Digital_Circuits/Latches]

Circuit Diagram for the Gated D Latch (with the latch implemented using NORs)



The NOT gate is now in a different place.
Also, S and R are swapped.

[Figure 5.7a from the textbook]

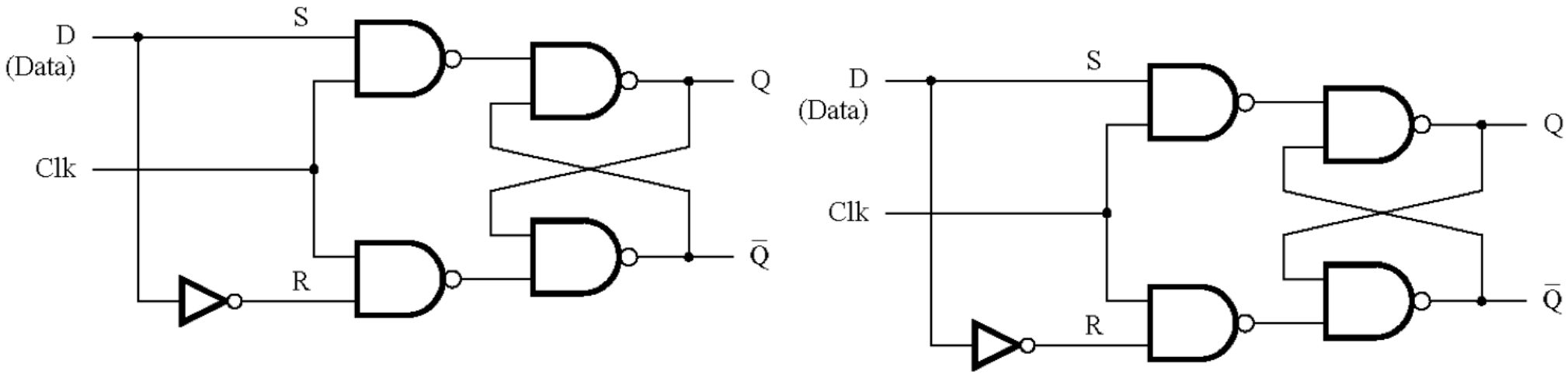
[https://en.wikibooks.org/wiki/Digital_Circuits/Latches]

Master-Slave D Flip-Flop

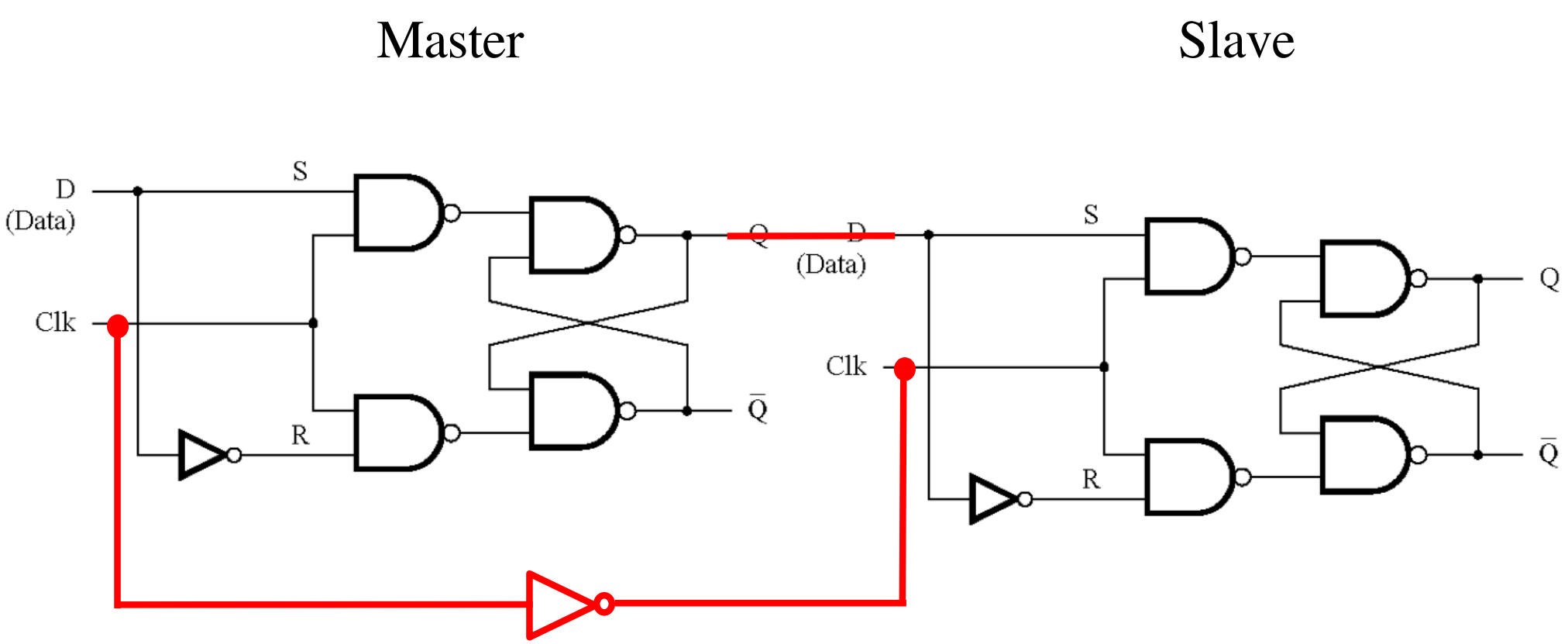
Constructing a Master-Slave D Flip-Flop From Two D Latches

Master

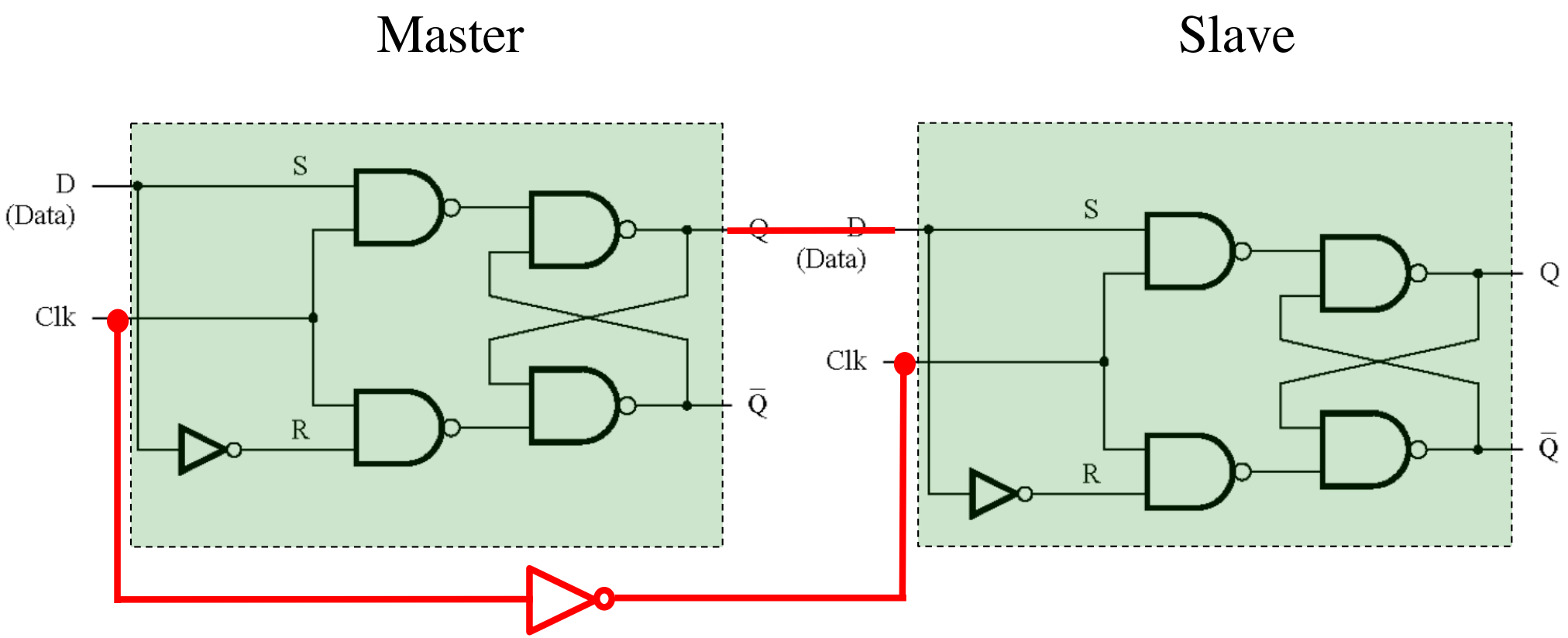
Slave



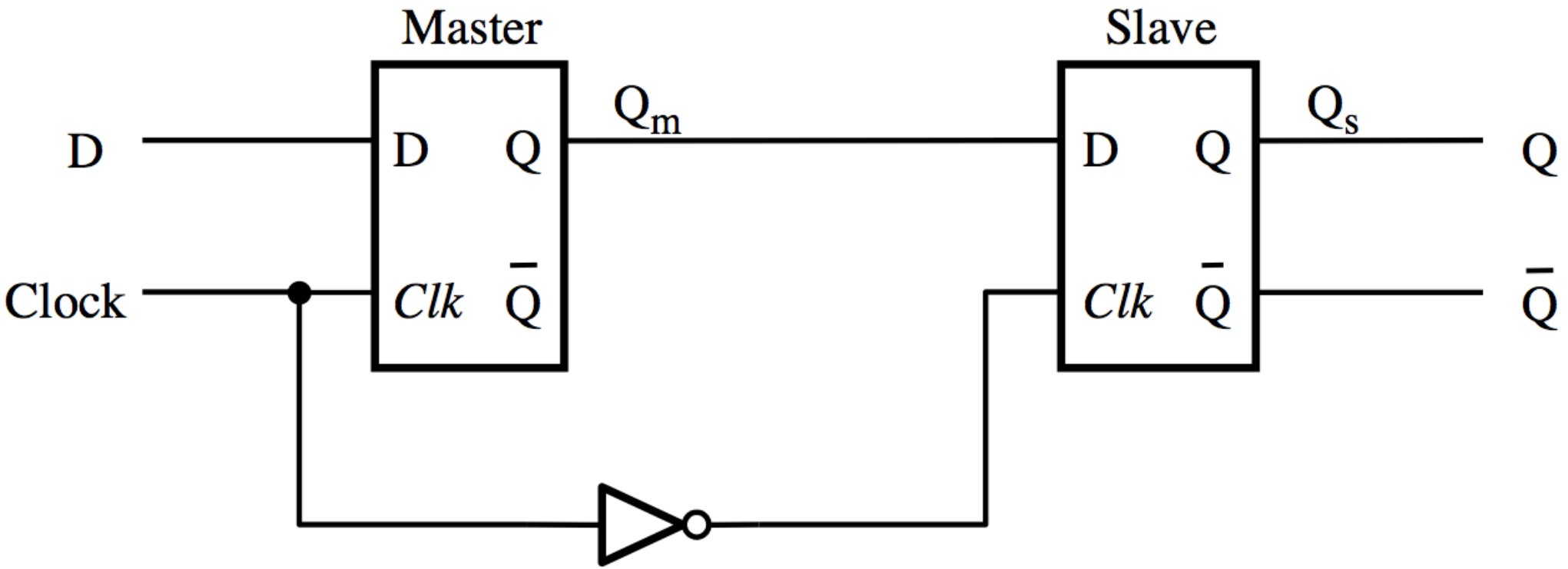
Constructing a Master-Slave D Flip-Flop From Two D Latches



Constructing a Master-Slave D Flip-Flop From Two D Latches

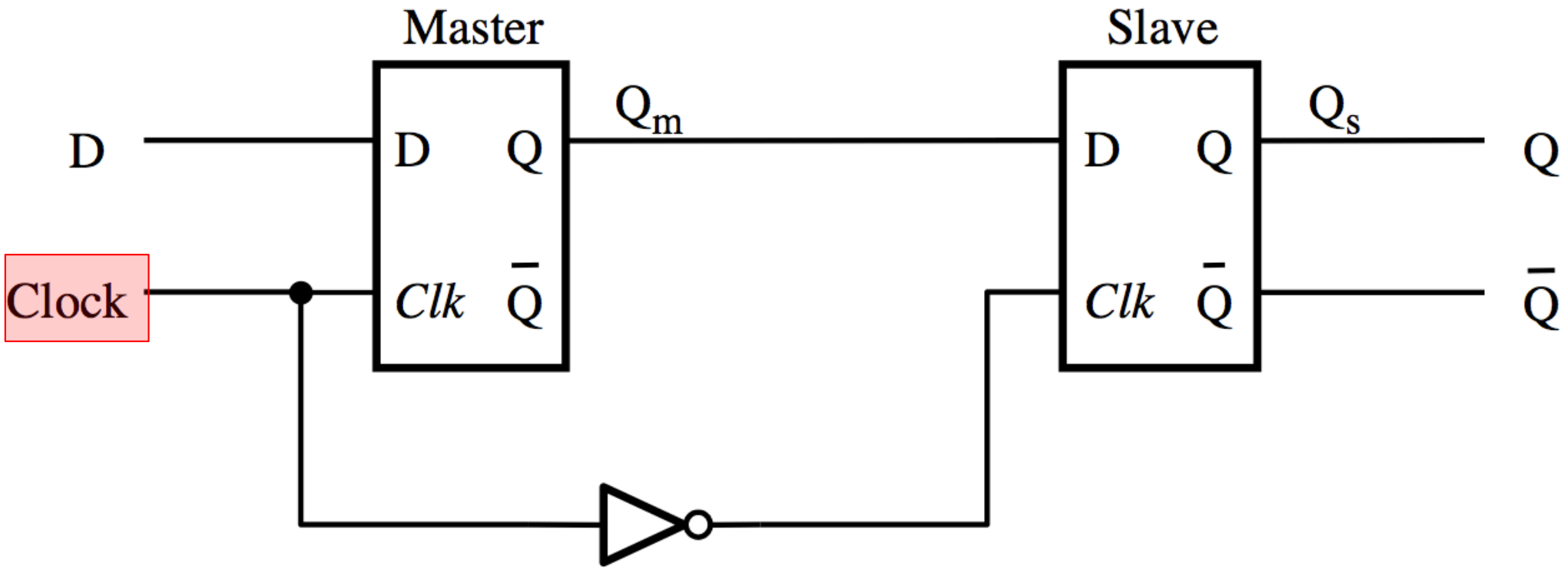


Constructing a Master-Slave D Flip-Flop From Two D Latches



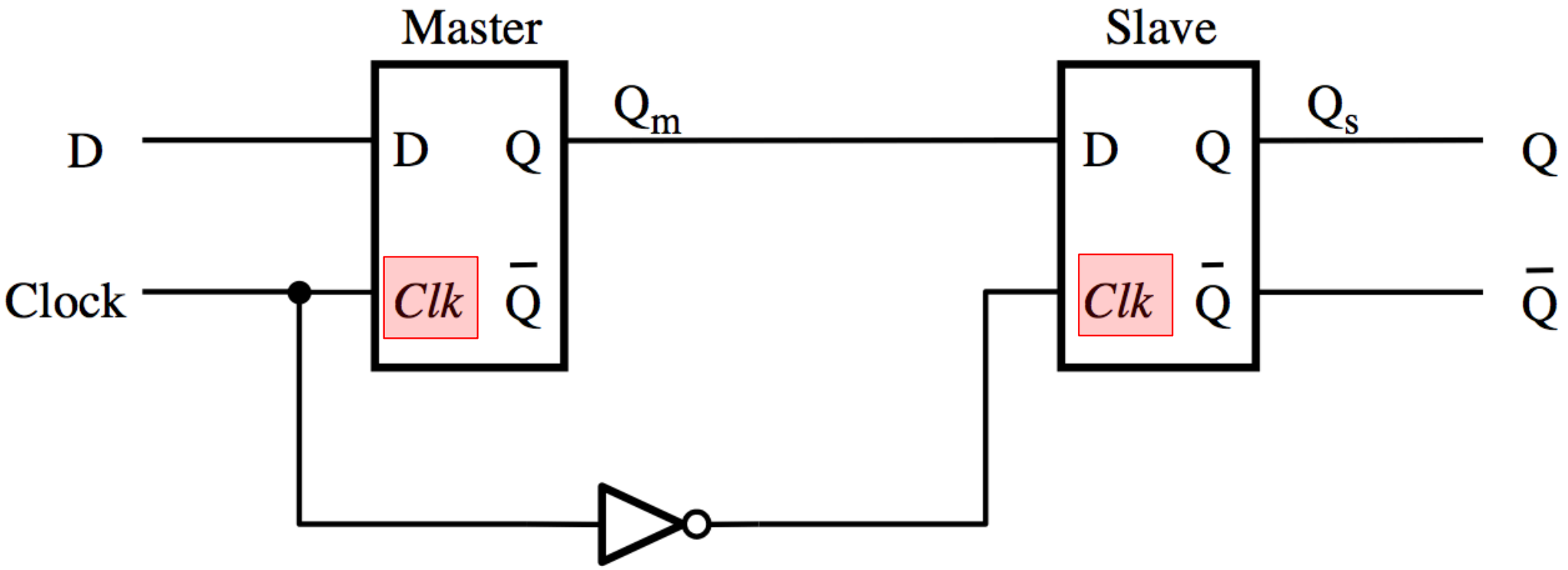
[Figure 5.9a from the textbook]

Clock is used for the D Flip-Flop



[Figure 5.9a from the textbook]

Clock is used for the D Flip-Flop, but Clk is used for each D Latch



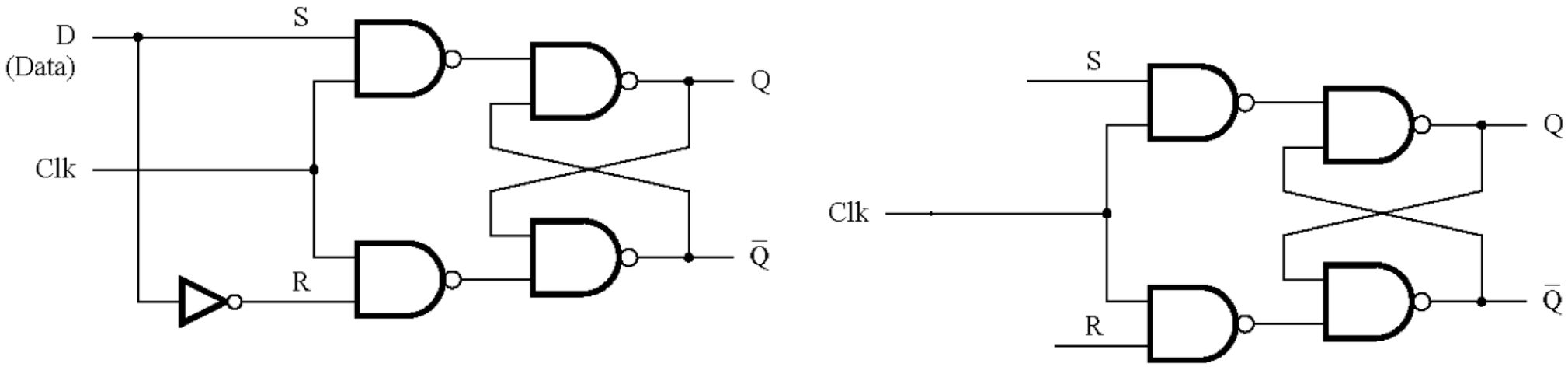
[Figure 5.9a from the textbook]

Constructing a Master-Slave D Flip-Flop From one D Latch and one Gated SR Latch

(This version uses one less NOT gate)

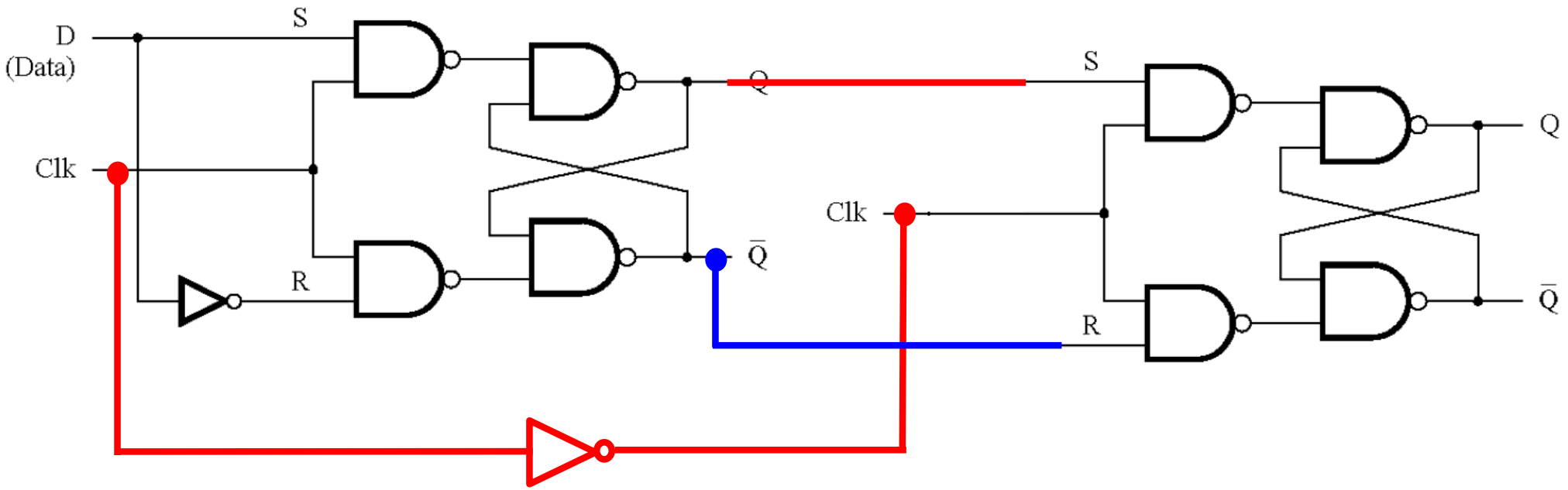
Master

Slave



Constructing a Master-Slave D Flip-Flop From one D Latch and one Gated SR Latch

(This version uses one less NOT gate)

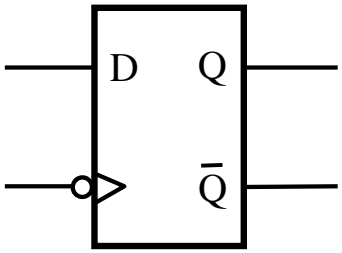


Edge-Triggered D Flip-Flops

Motivation

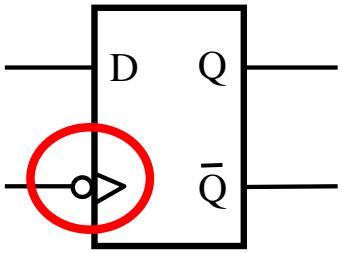
In some cases we need to use a memory storage device that can change its state no more than once during each clock cycle.

Graphical Symbol for the Master-Slave D Flip-Flop



[Figure 5.9c from the textbook]

Graphical Symbol for the Master-Slave D Flip-Flop

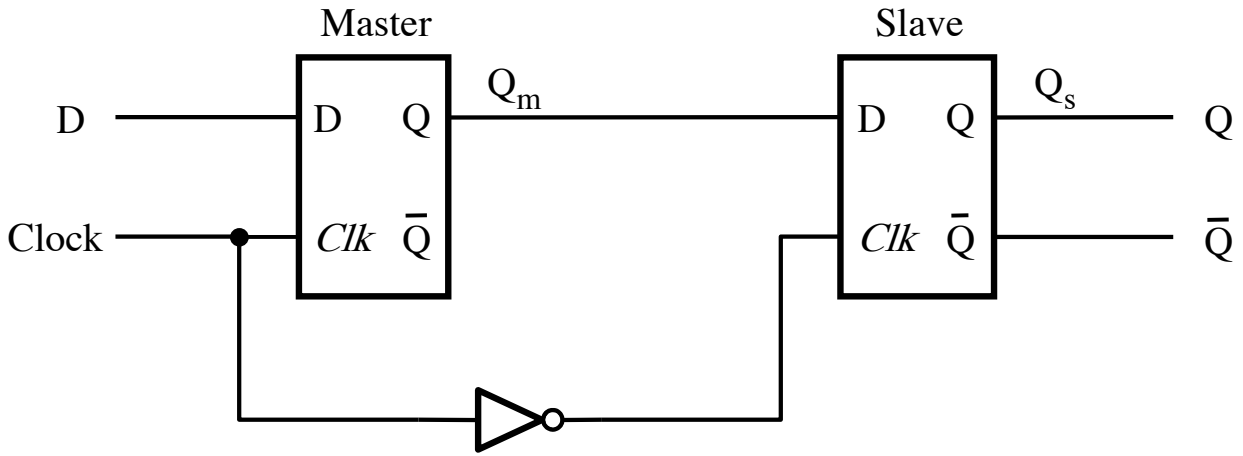


The > means that this is edge-triggered

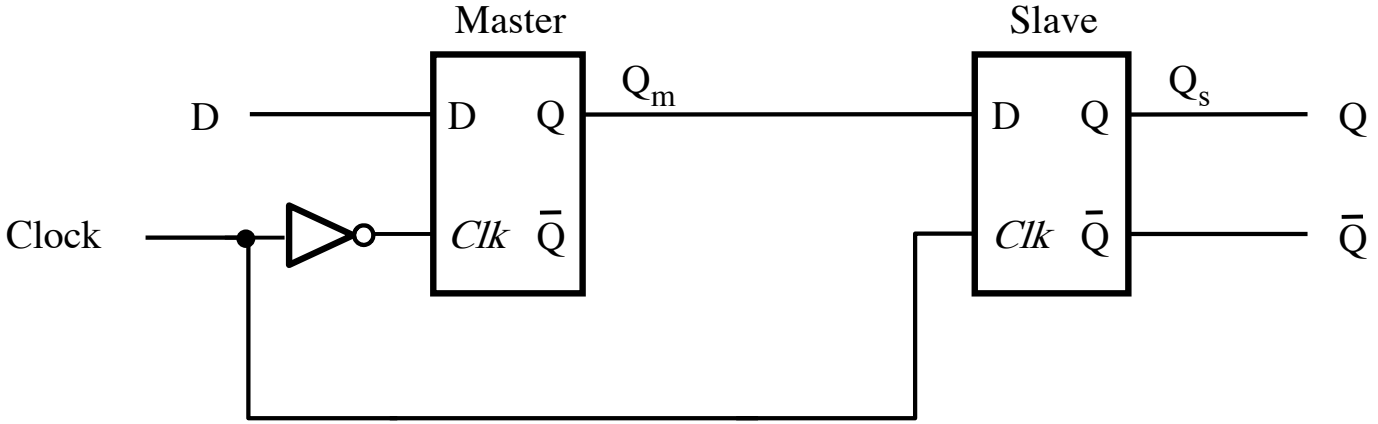
The small circle means that is is the negative edge

[Figure 5.9c from the textbook]

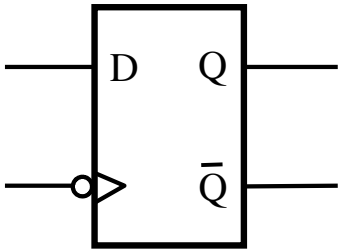
Negative-Edge-Triggered Master-Slave D Flip-Flop



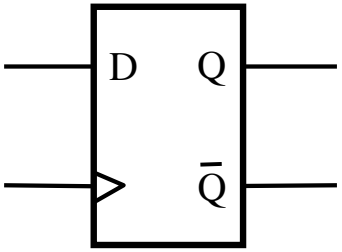
Positive-Edge-Triggered Master-Slave D Flip-Flop



Negative-Edge-Triggered Master-Slave D Flip-Flop



Positive-Edge-Triggered Master-Slave D Flip-Flop

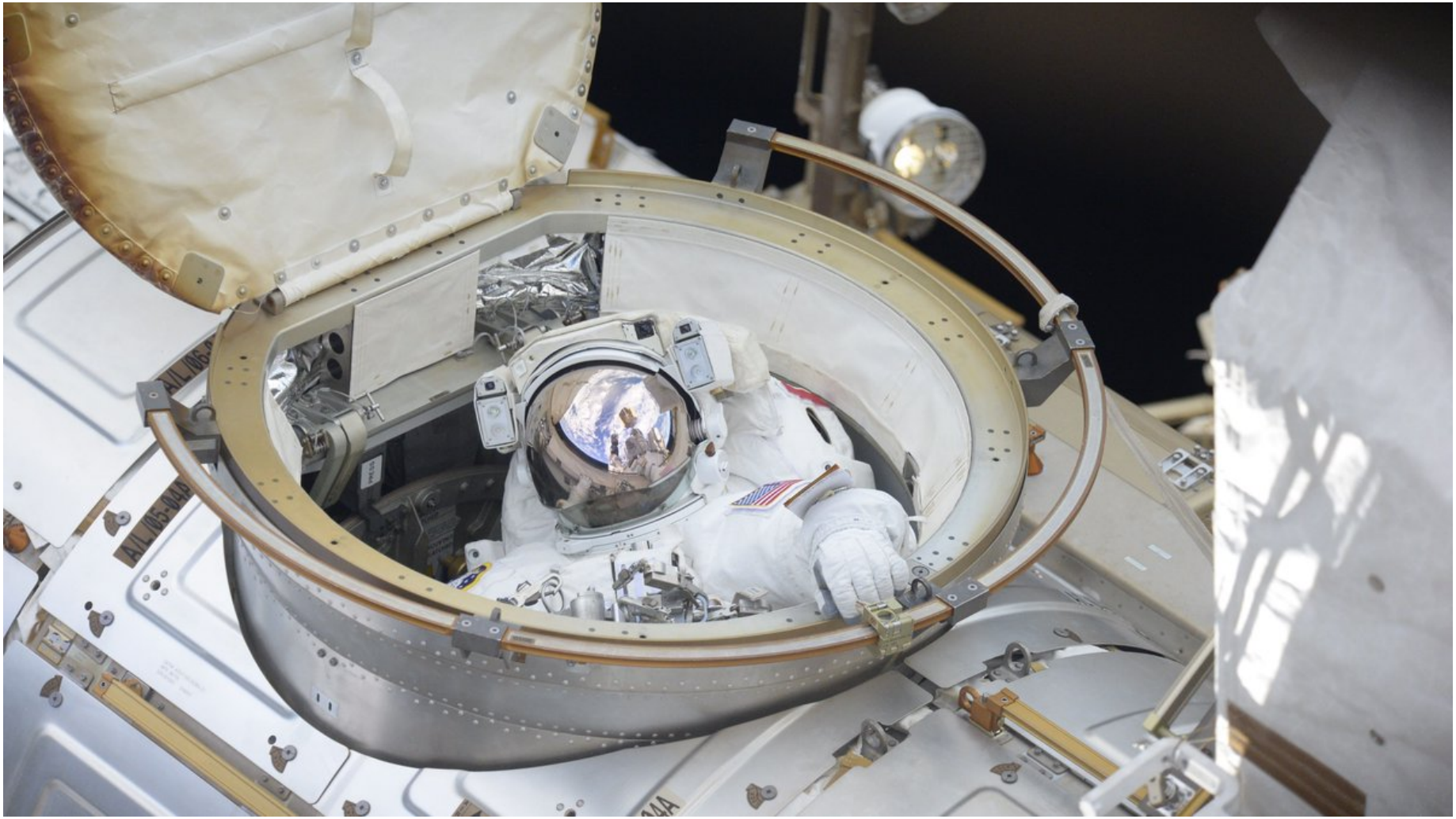


Flip-Flop Analogy

(Airlock)

[https://en.wikipedia.org/wiki/Quest_Joint_Airlock]

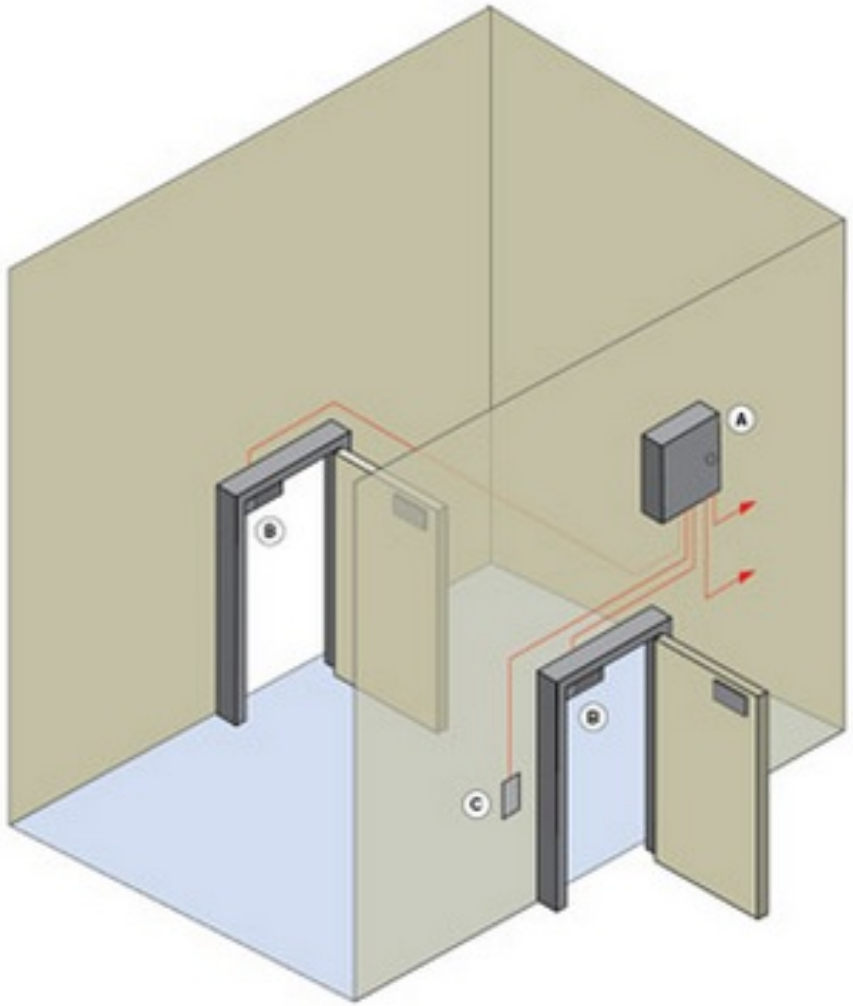
[https://www.allposters.com/-sp/Astronaut-Ingresses-the-Airlock-Hatch-on-the-International-Space-Station-Posters_i12684251_.htm]



[https://www.spaceflightinsider.com/missions/iss/astronauts-install-high-definition-cameras-outside-international-space-station/]

[https://en.wikipedia.org/wiki/Quest_Joint_Airlock]

Airlock on Earth



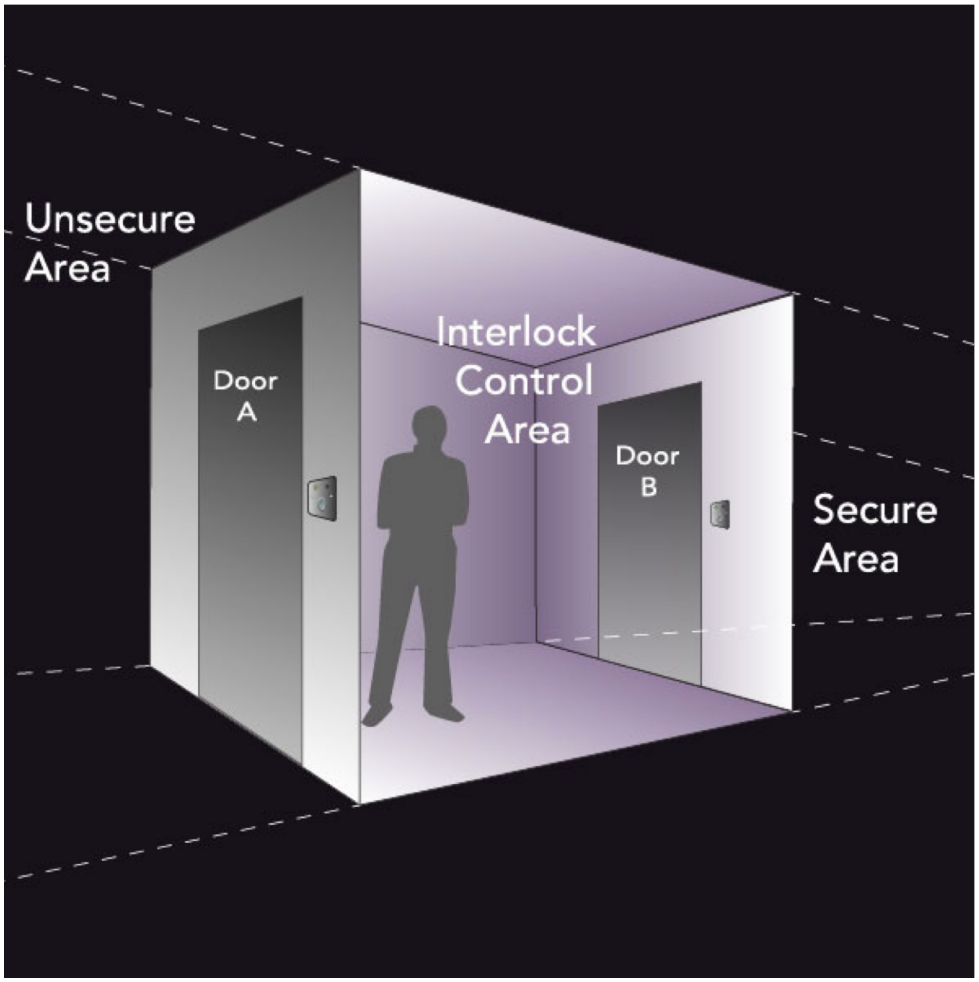
[https://www.maglocks.com/sdc-two-door-airlockmantrapcleanroom-level-1-kit.html]

D Flip-Flop Analogy

Outer Door
Will Not Unlock When
Inner Door is Open

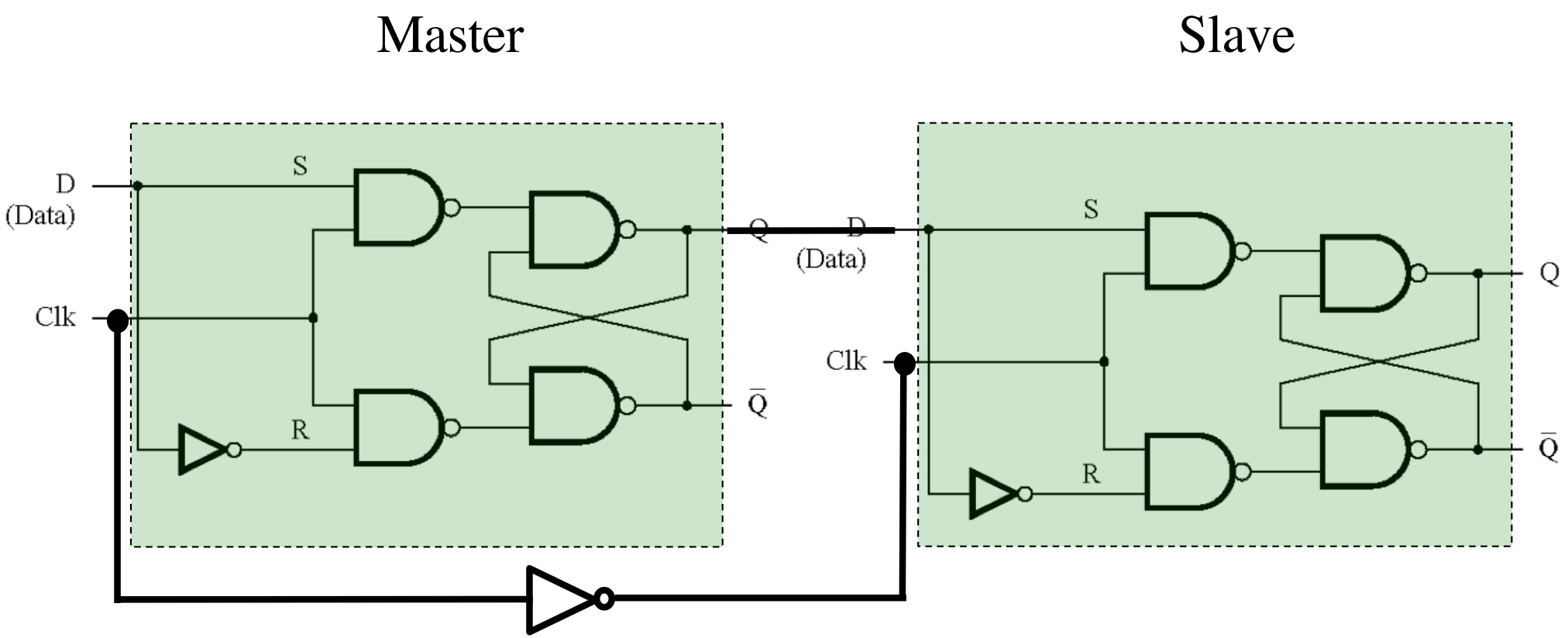
Inner Door
Will Not Unlock When
OuterDoor is Open

[https://www.nortechcontrol.com/solutions/people/door-interlock/]



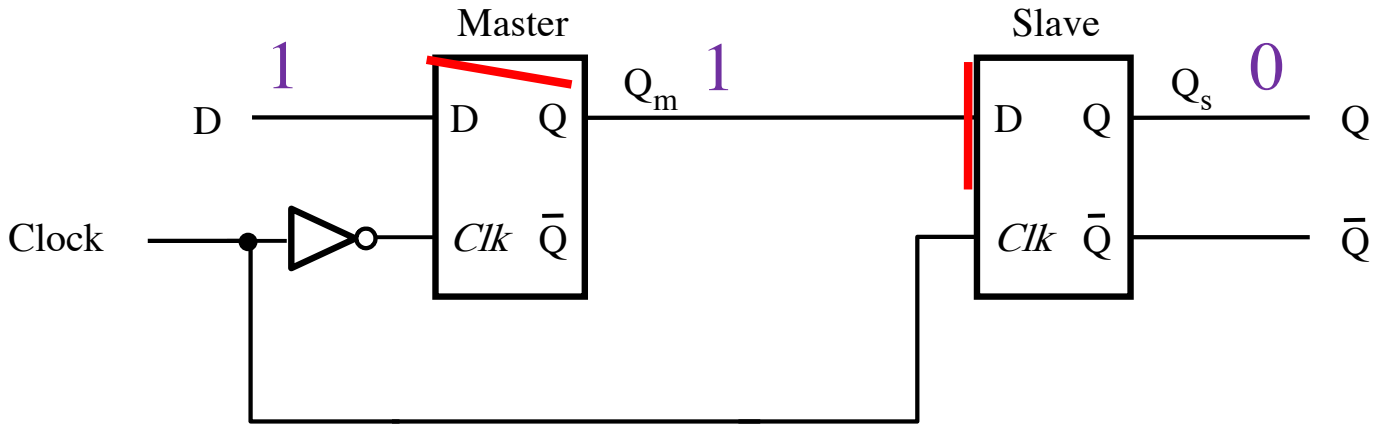
[https://www.insafe.com/activa-pro-interlock/]

D Flip-Flop Analogy

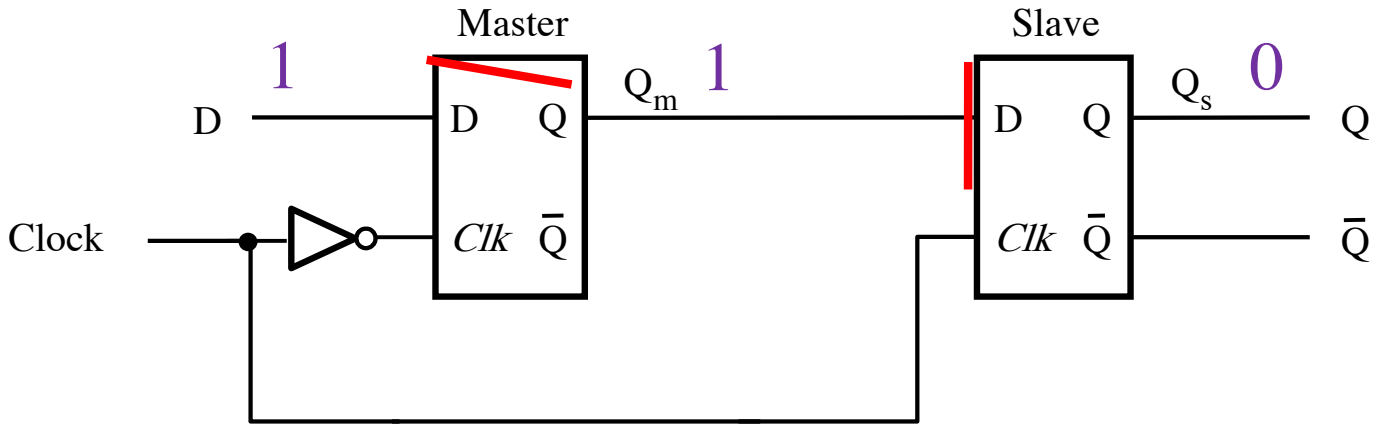


D Flip-Flop:
A Double Door Analogy

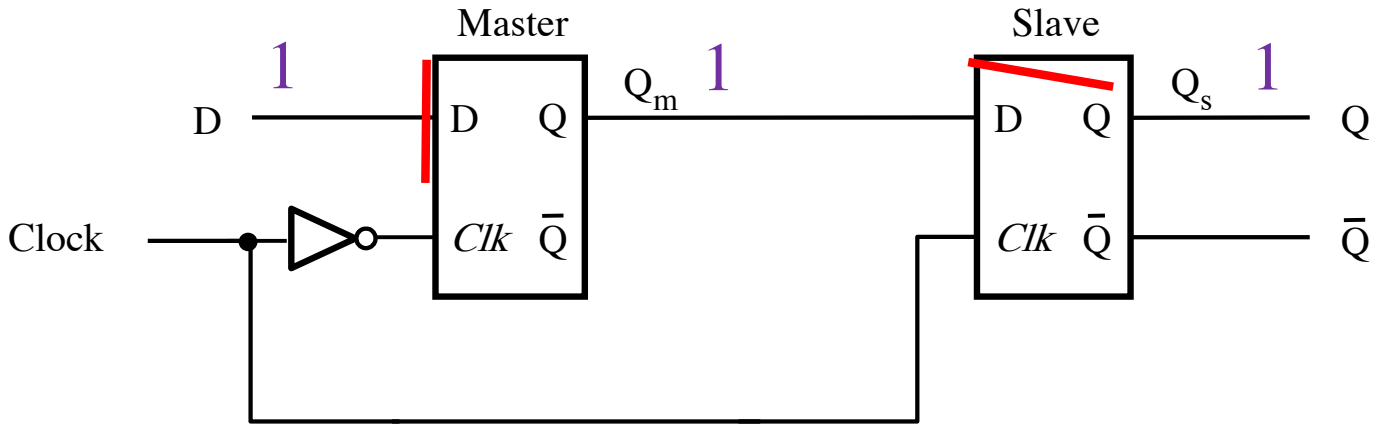
Positive-Edge-Triggered Master-Slave D Flip-Flop

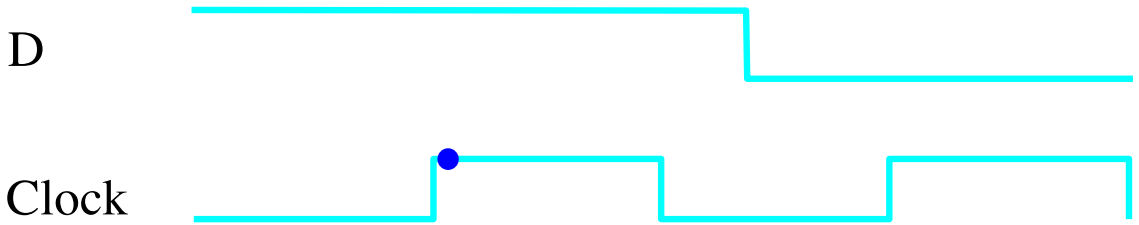


Positive-Edge-Triggered Master-Slave D Flip-Flop

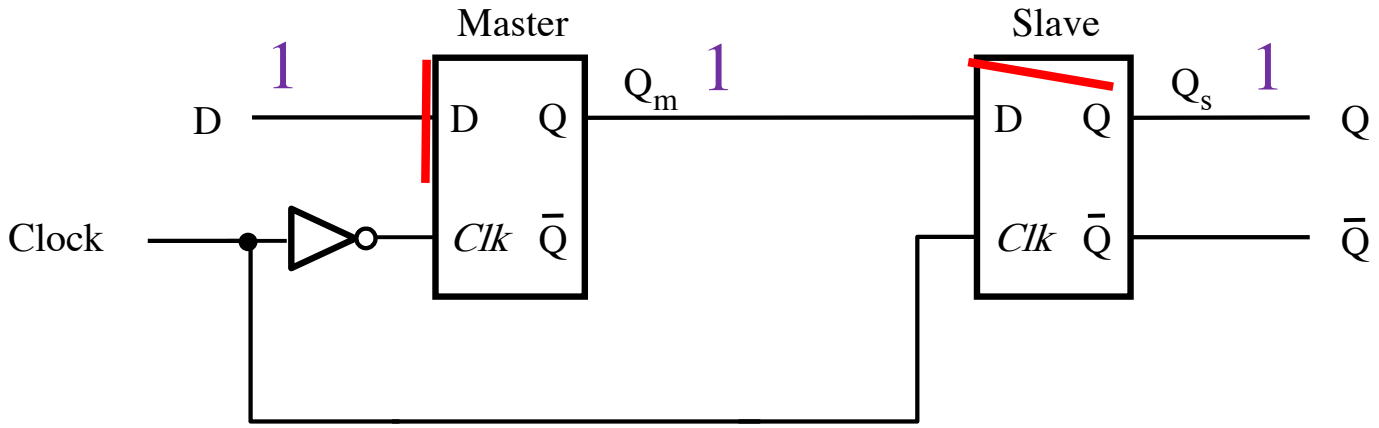


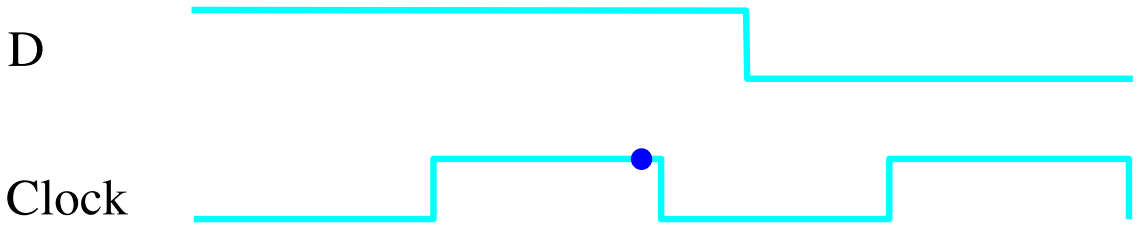
Positive-Edge-Triggered Master-Slave D Flip-Flop



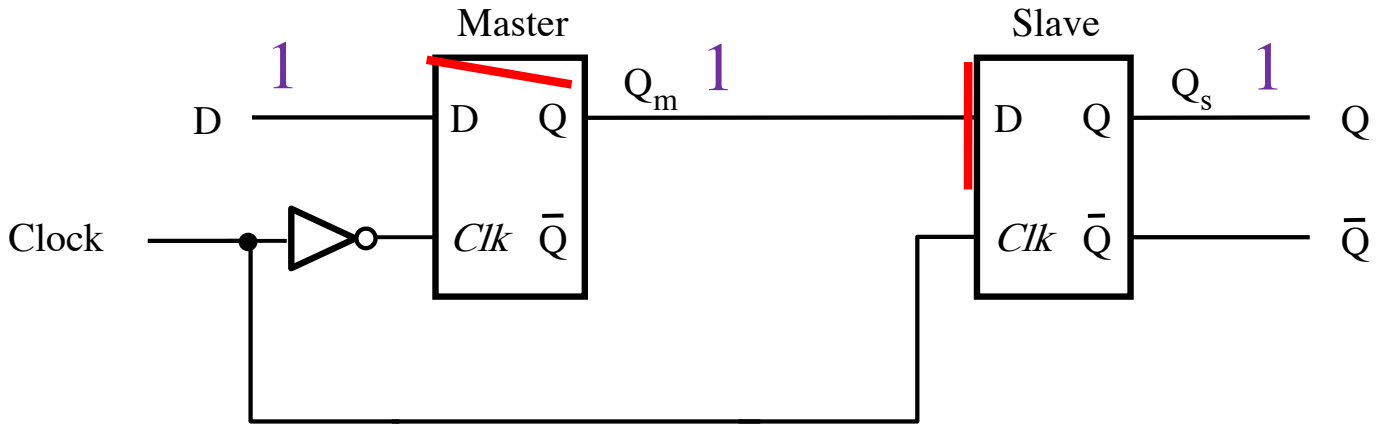


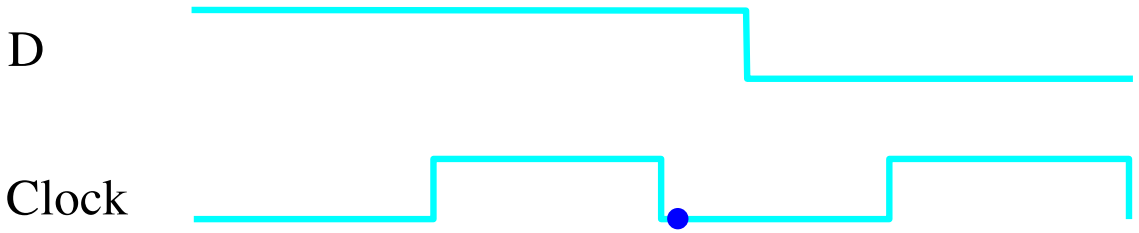
Positive-Edge-Triggered Master-Slave D Flip-Flop



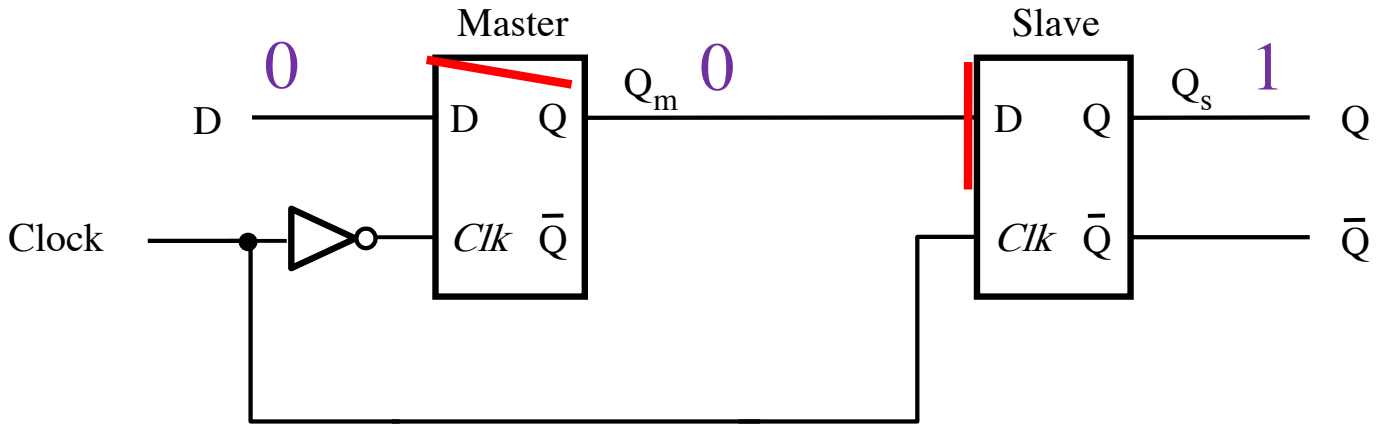


Positive-Edge-Triggered Master-Slave D Flip-Flop

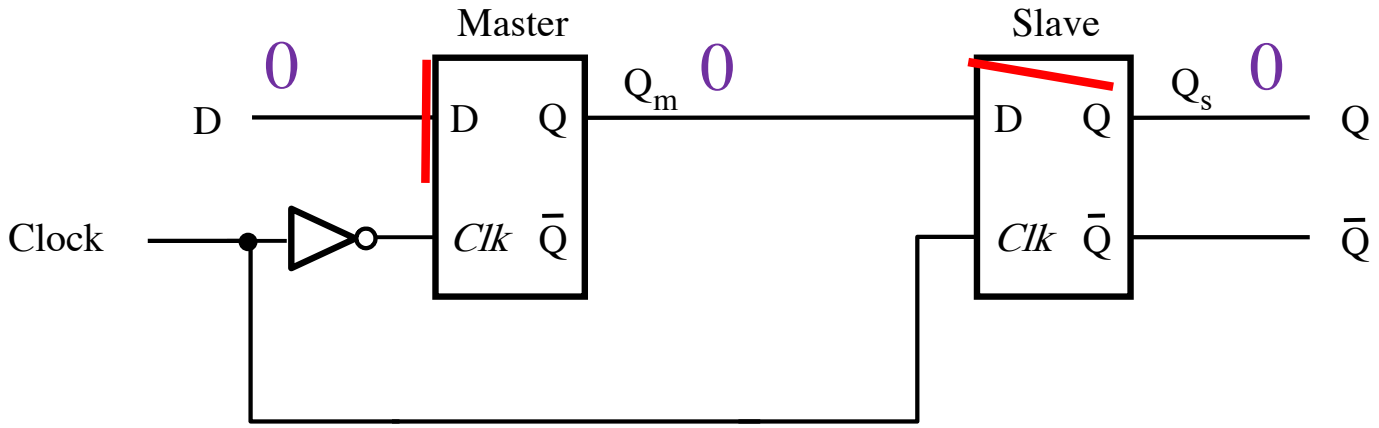




Positive-Edge-Triggered Master-Slave D Flip-Flop



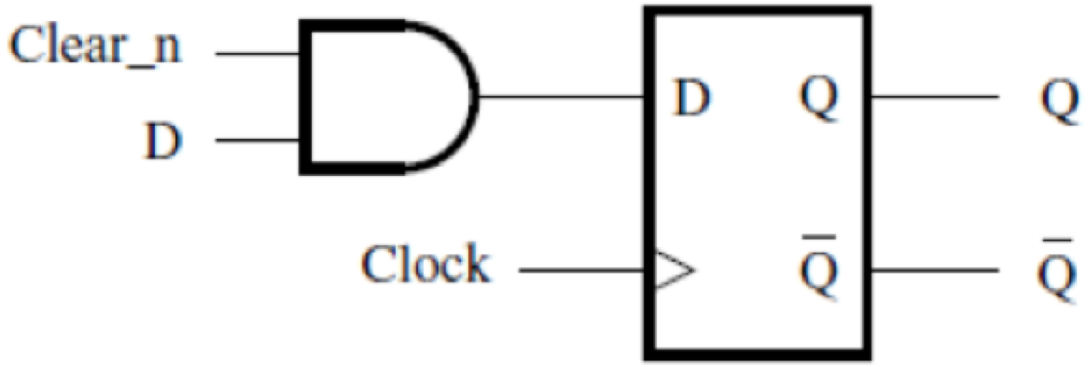
Positive-Edge-Triggered Master-Slave D Flip-Flop



Positive-edge-triggered D flip-flop with Clear and Preset

Positive-edge-triggered D flip-flop with Clear_n and Preset_n

Positive-edge-triggered D flip-flop with Synchronous Clear

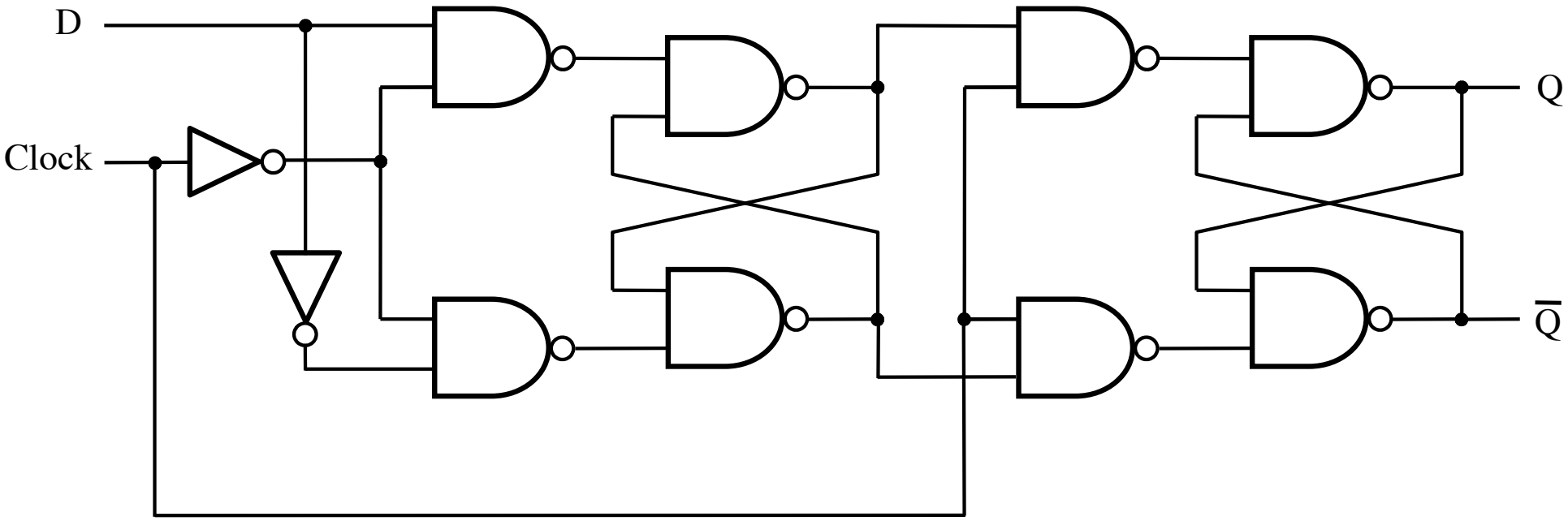


(c) Adding a synchronous clear

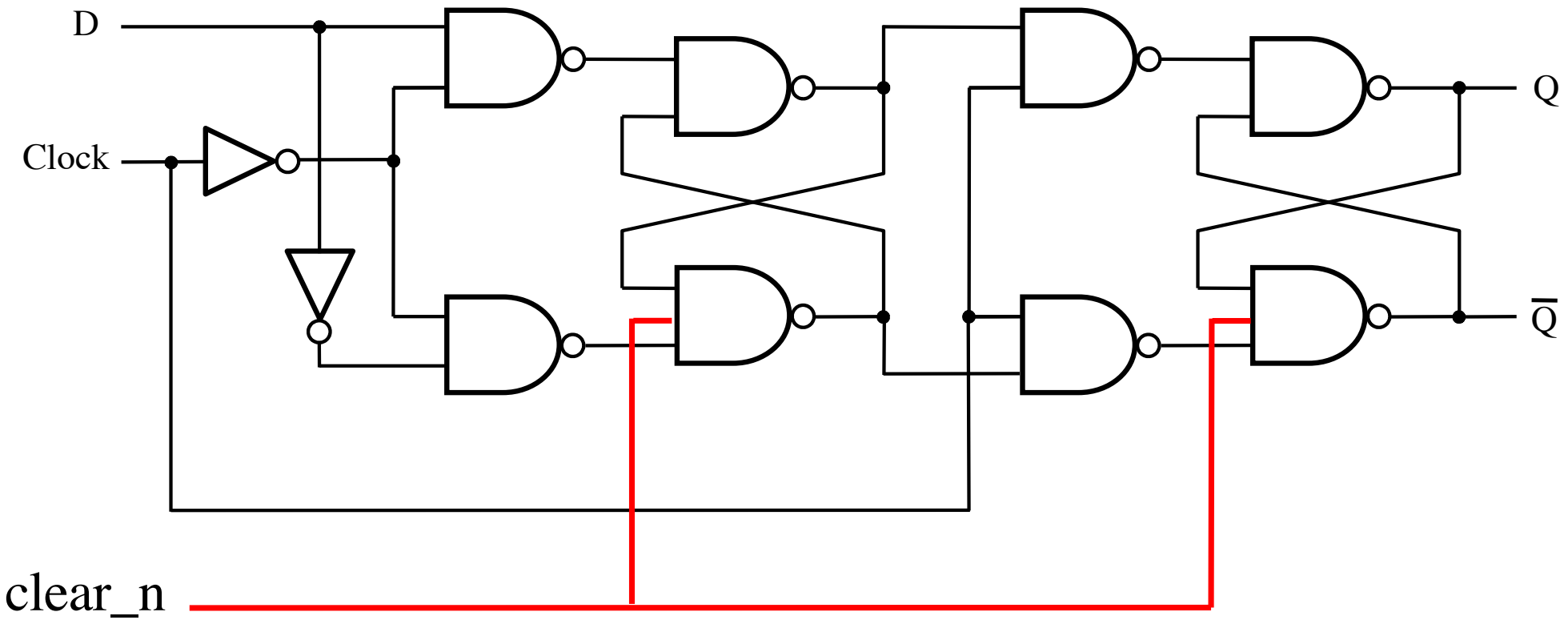
The output Q can be cleared only on the positive clock edge.

[Figure 5.13c from the textbook]

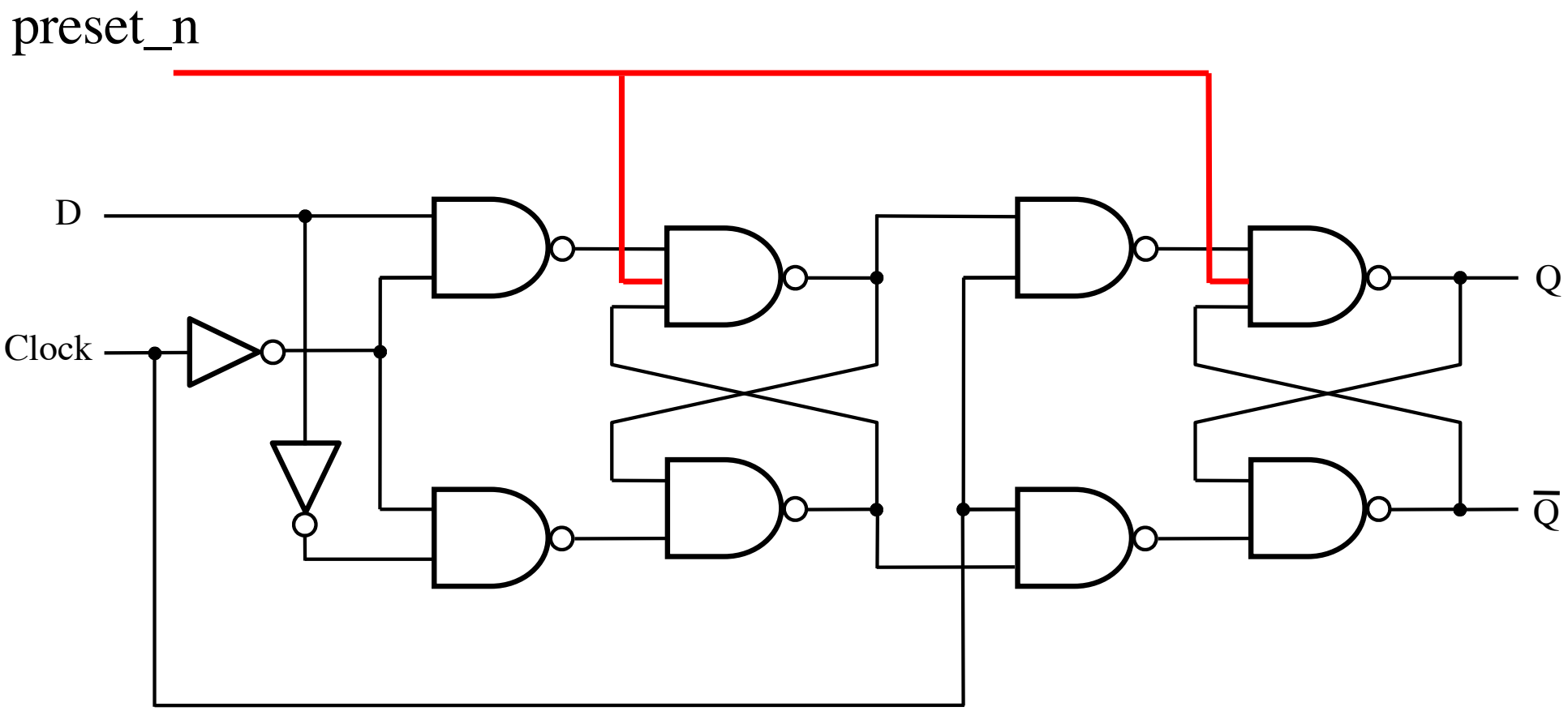
The Complete Wiring Diagram for a Positive-Edge-Triggered D Flip-Flop



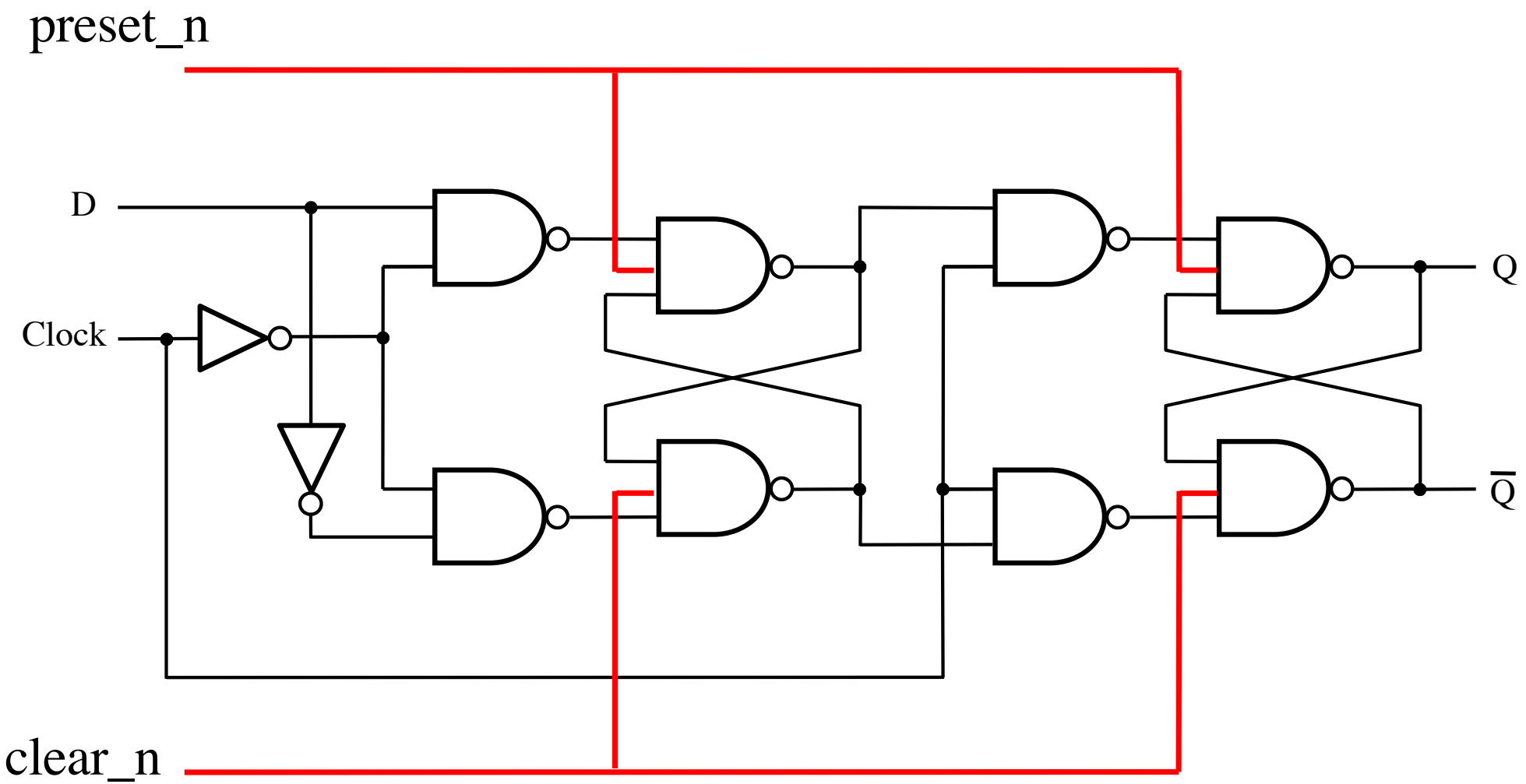
Adding an Asynchronous Clear



Adding an Asynchronous Preset

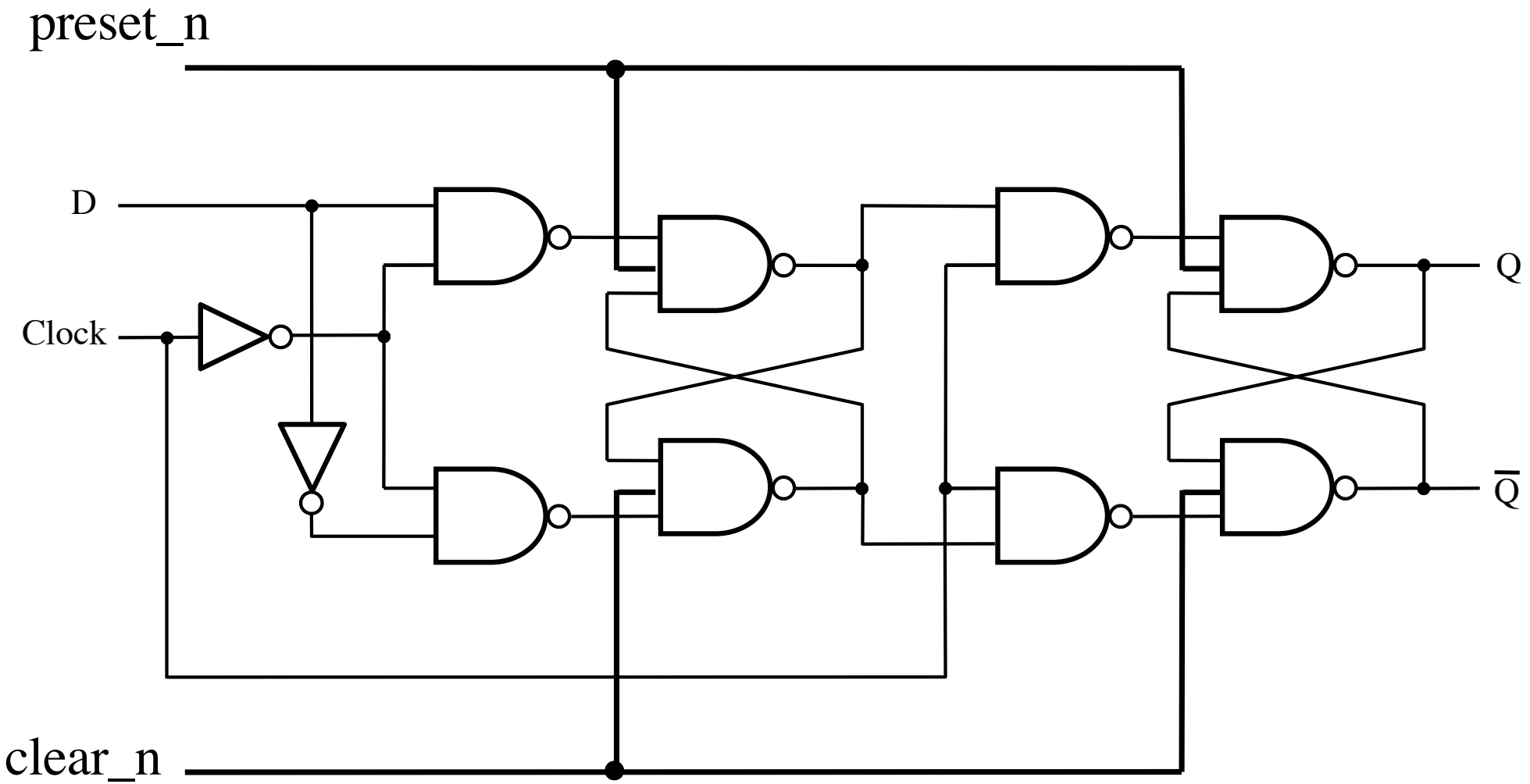


Positive-Edge-Triggered D Flip-Flop with Asynchronous Clear and Preset

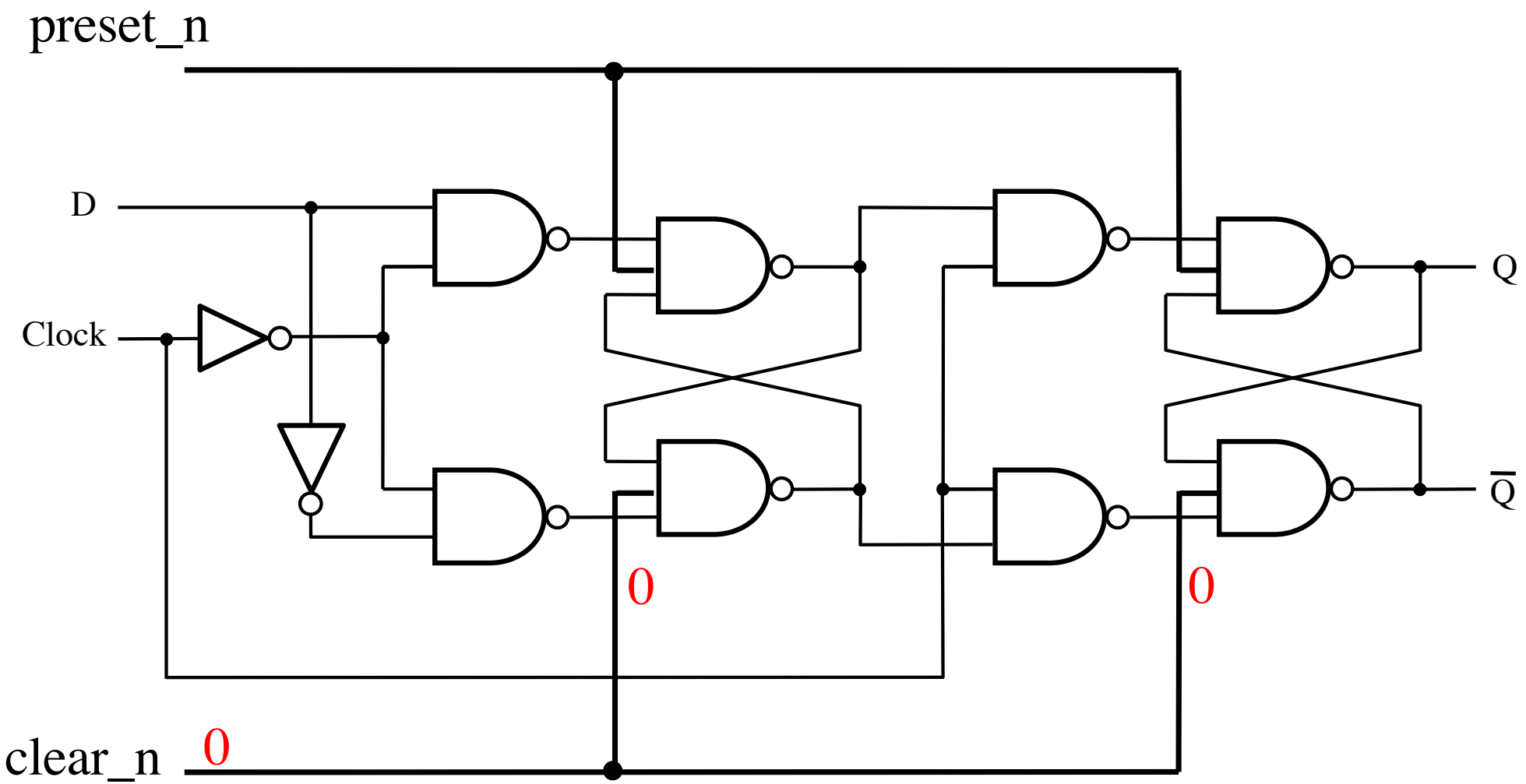


How does clear work?

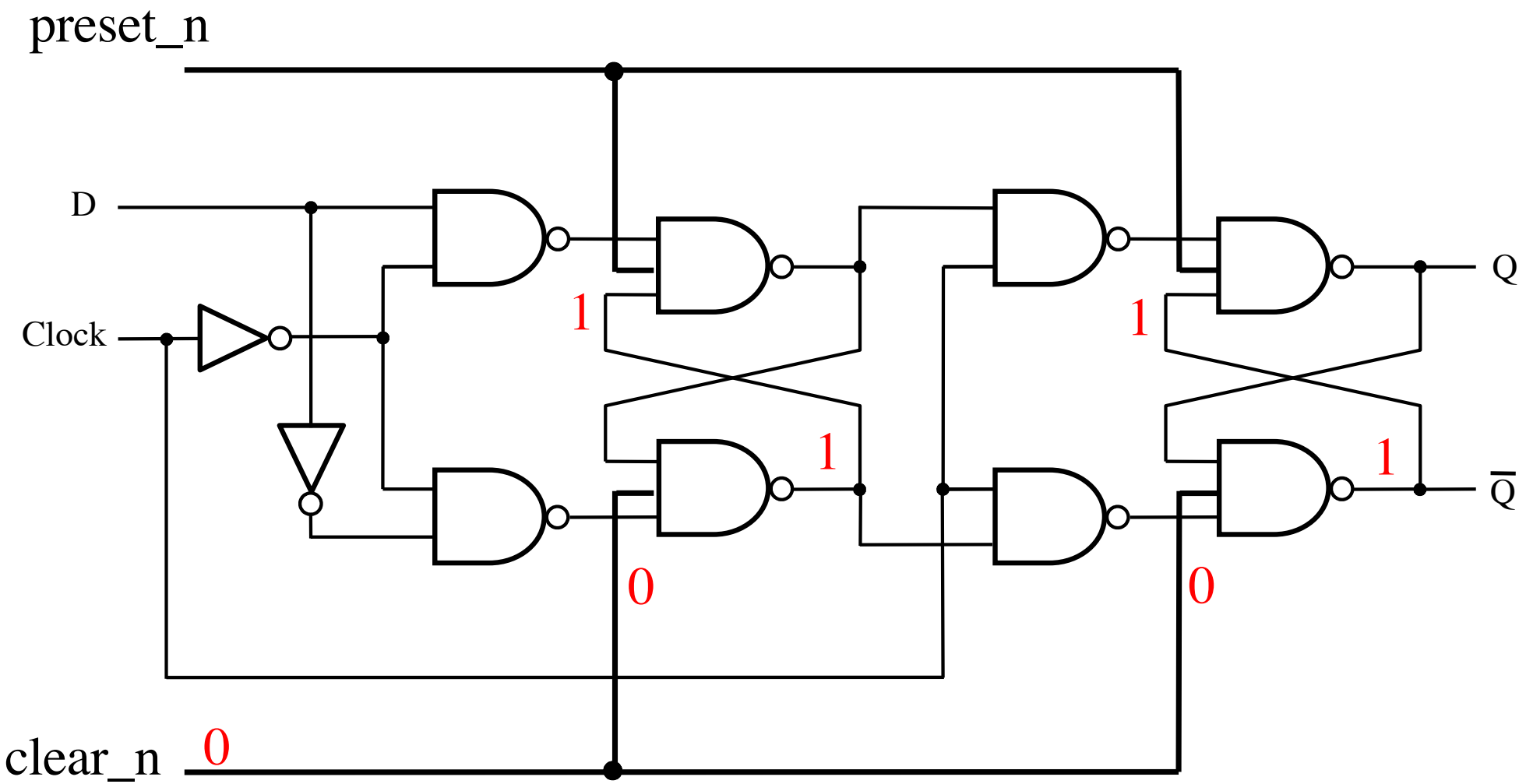
How does clear work?



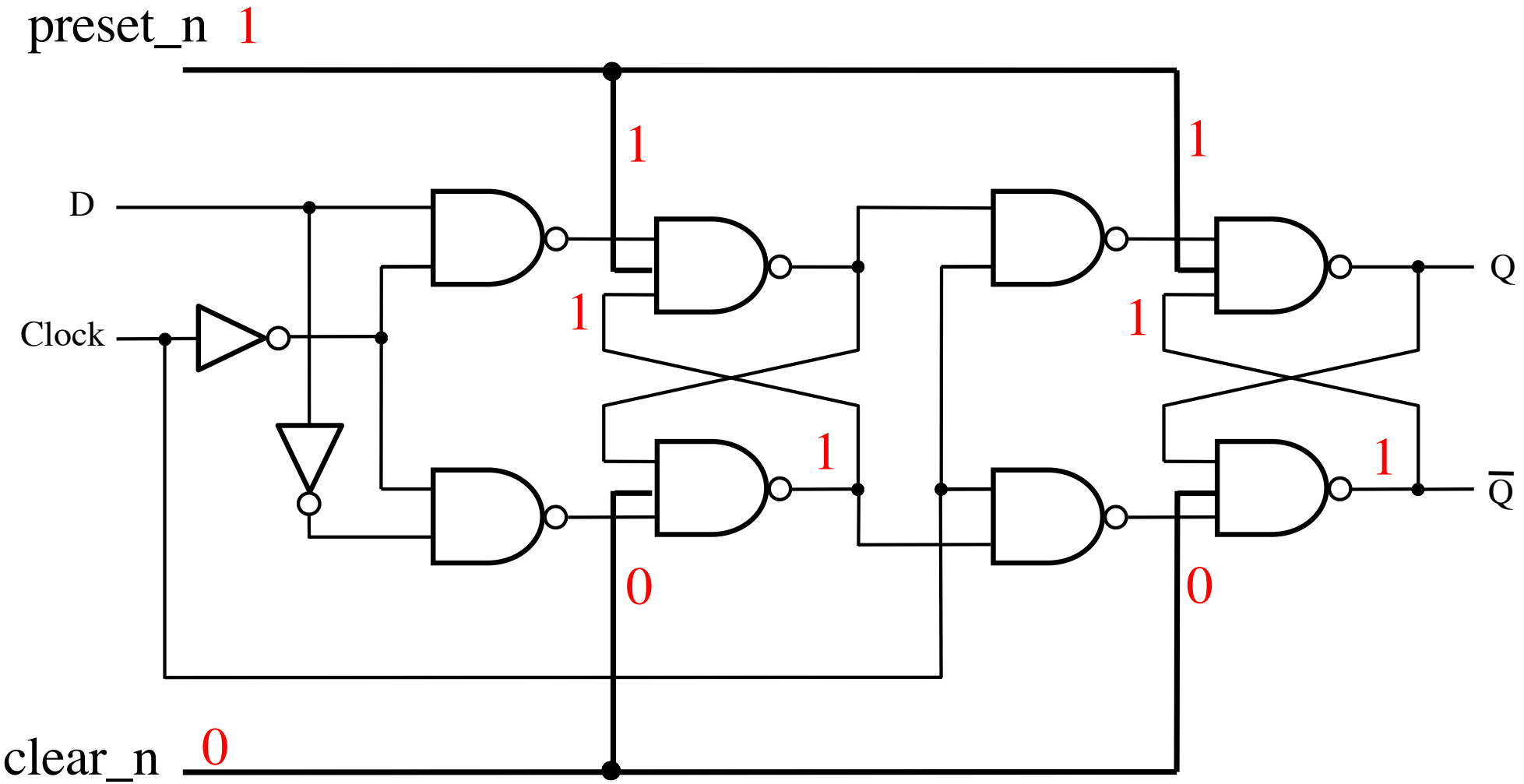
How does clear work?



How does clear work?

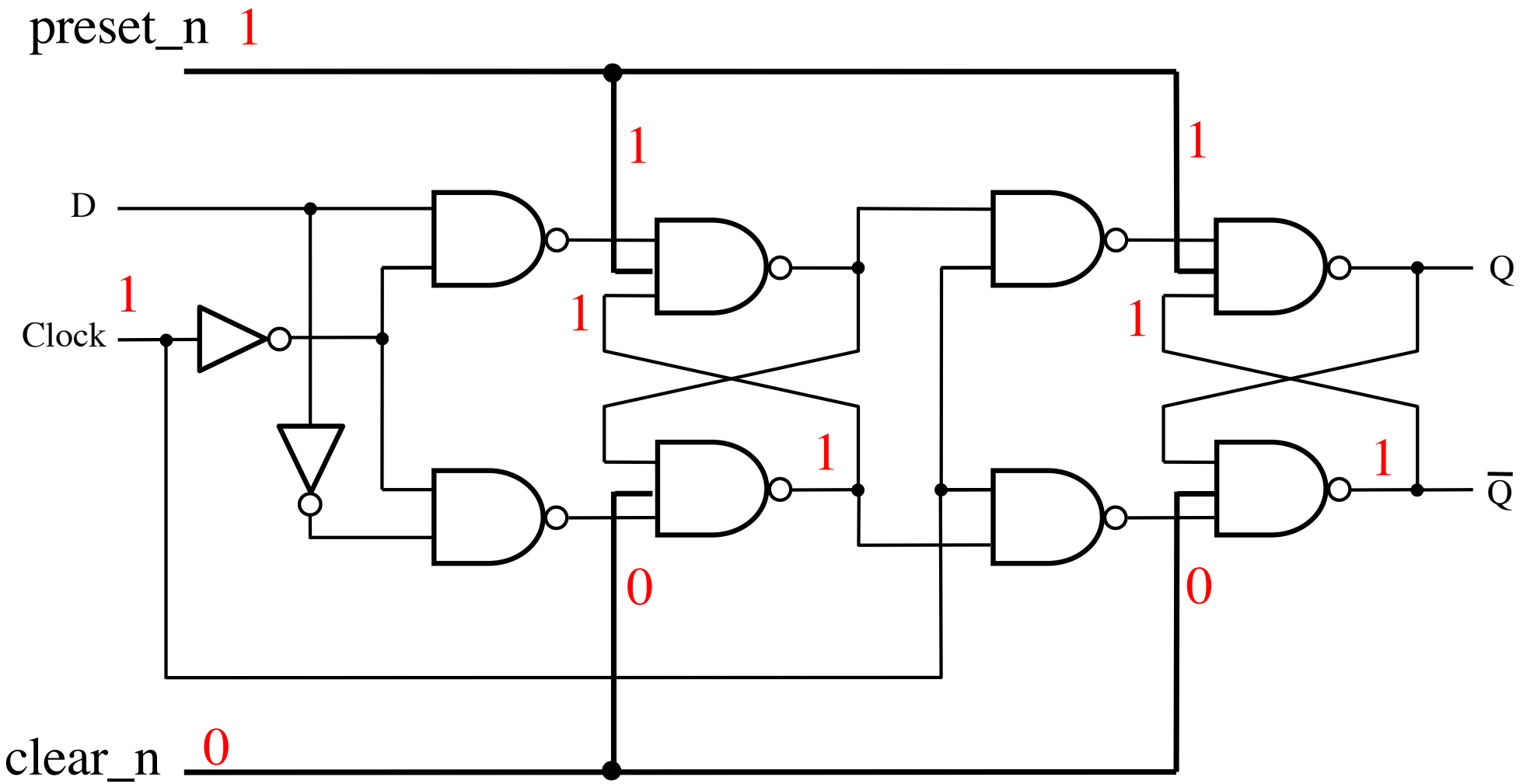


How does clear work?



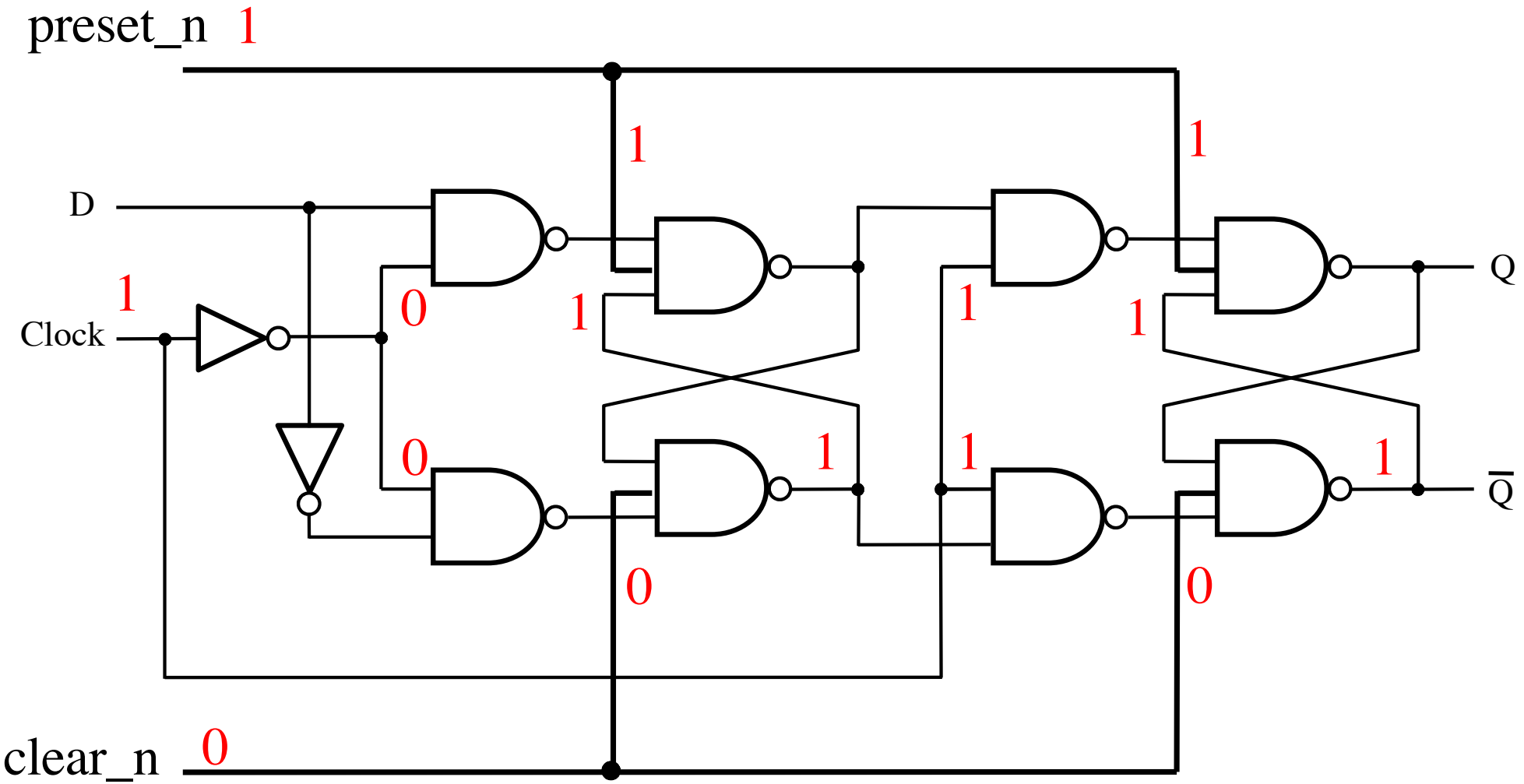
How does clear work?

At this point we need to consider two cases: Clock=1 v.s. Clock =0



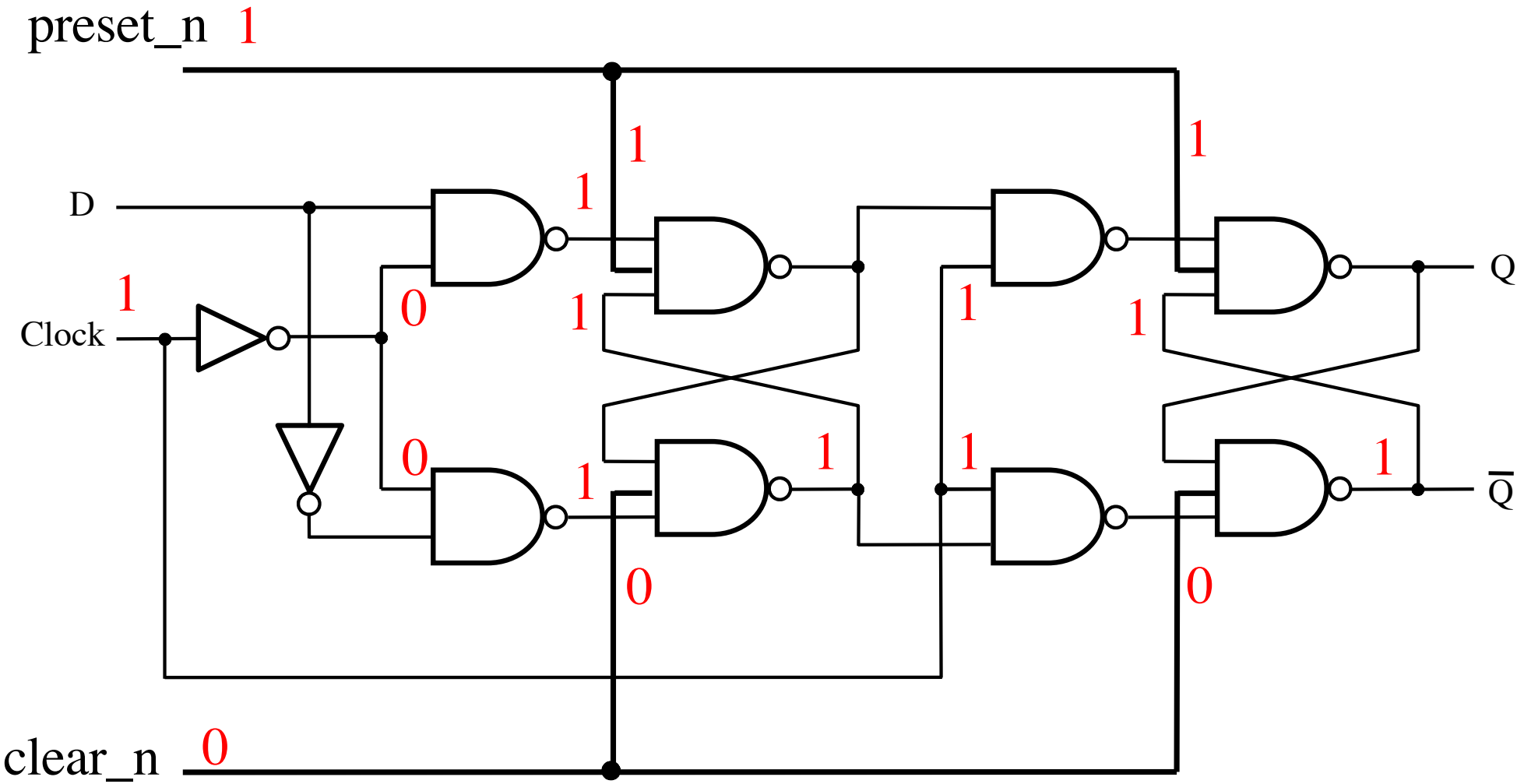
How does clear work?

Clock=1



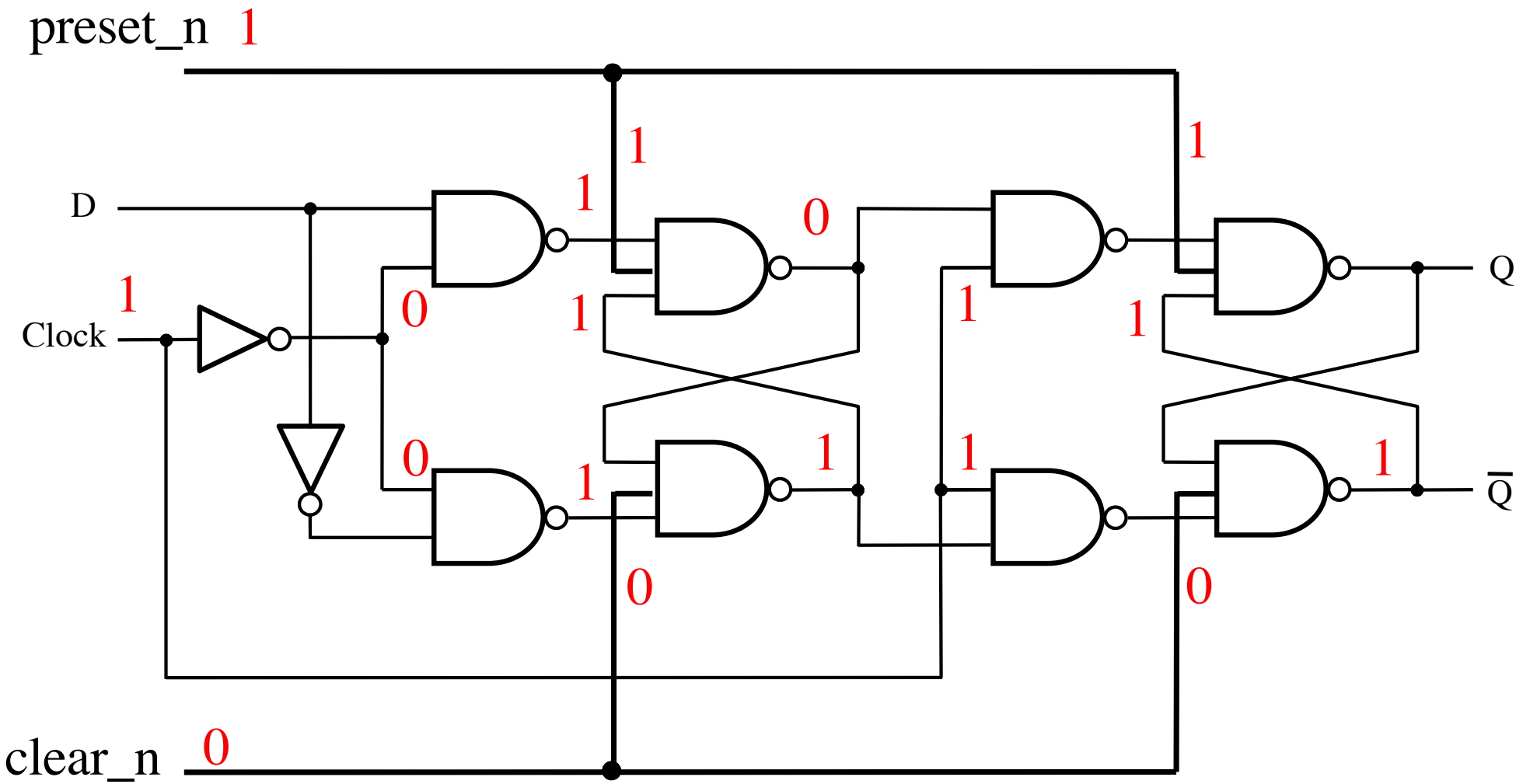
How does clear work?

Clock=1



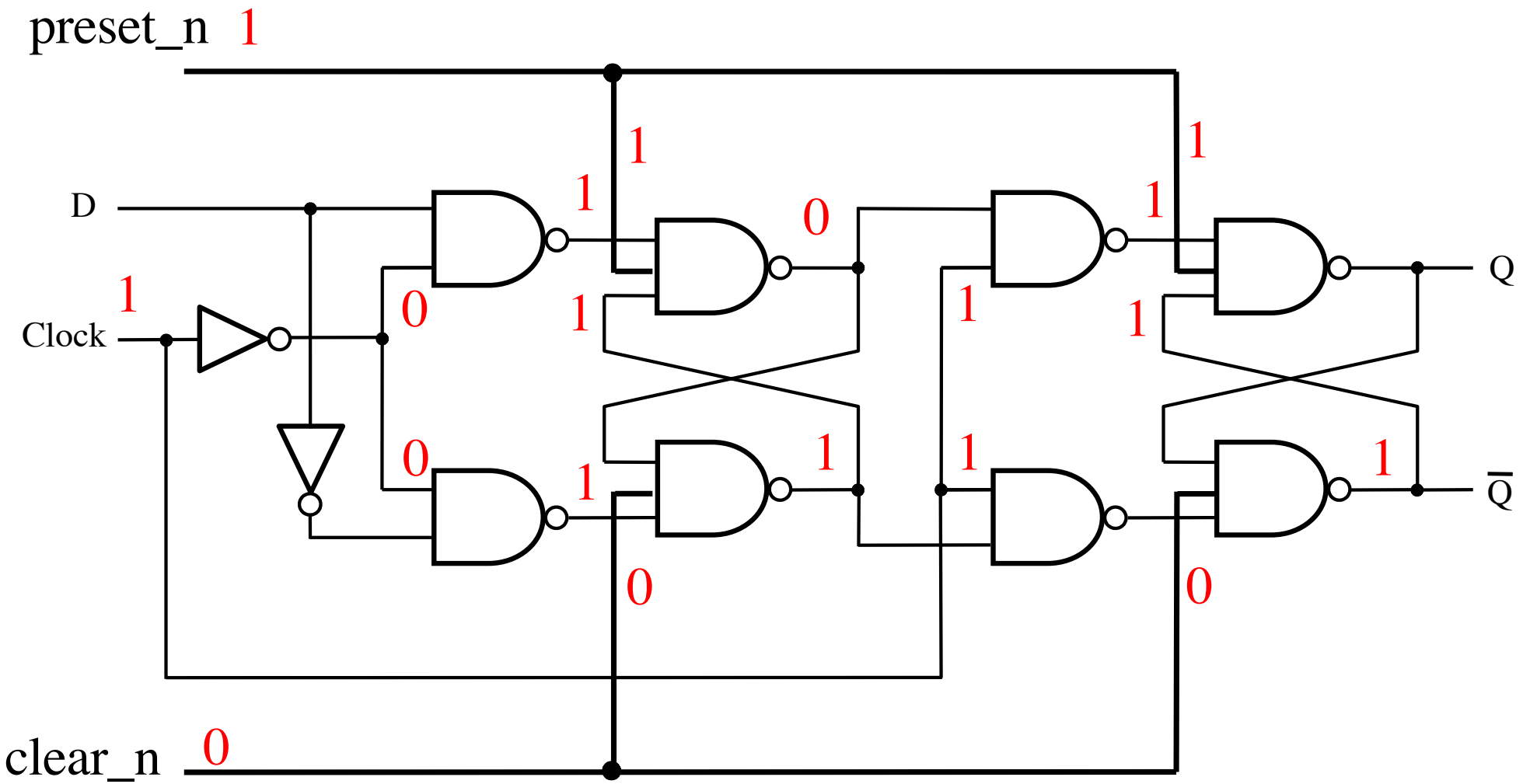
How does clear work?

Clock=1



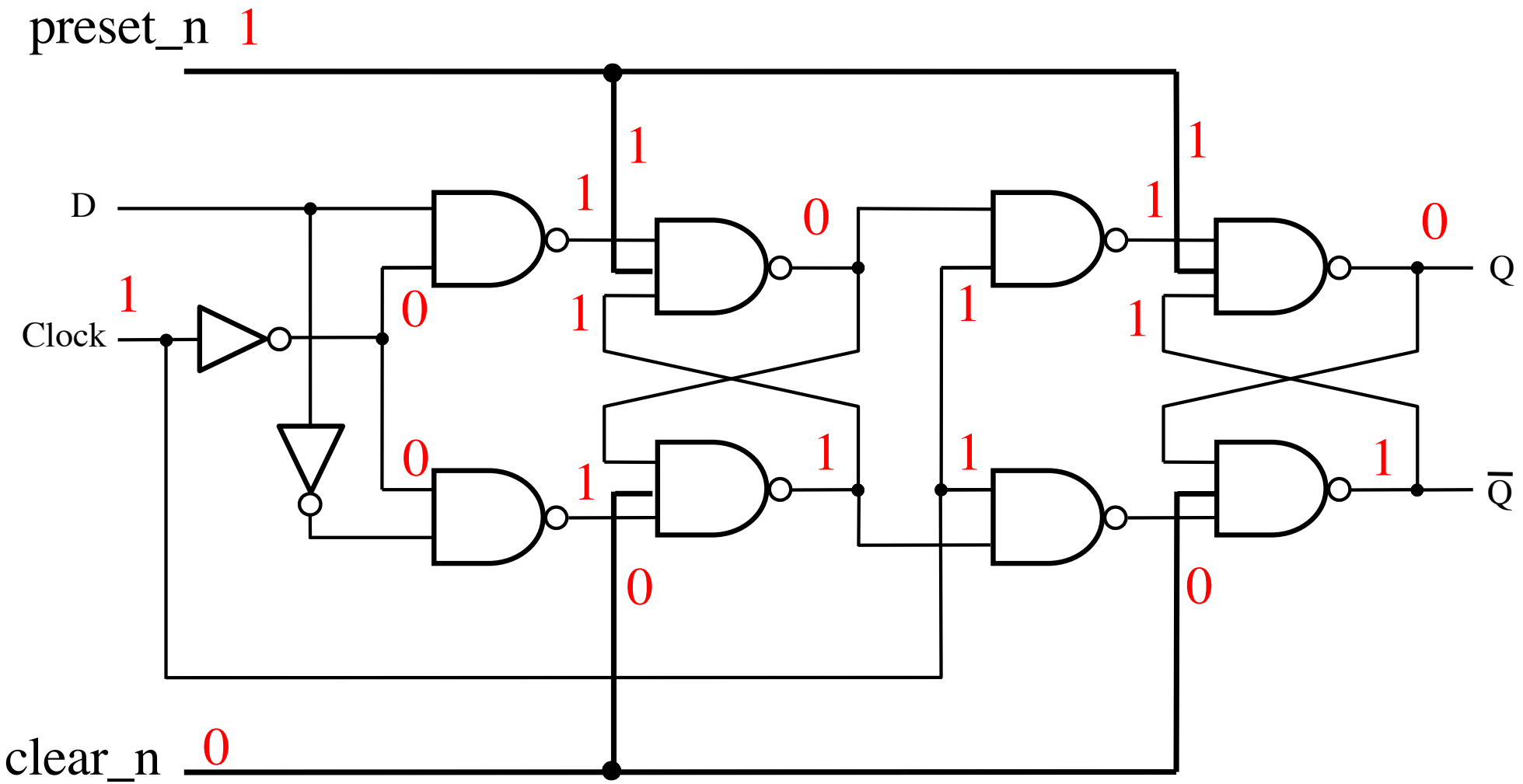
How does clear work?

Clock=1



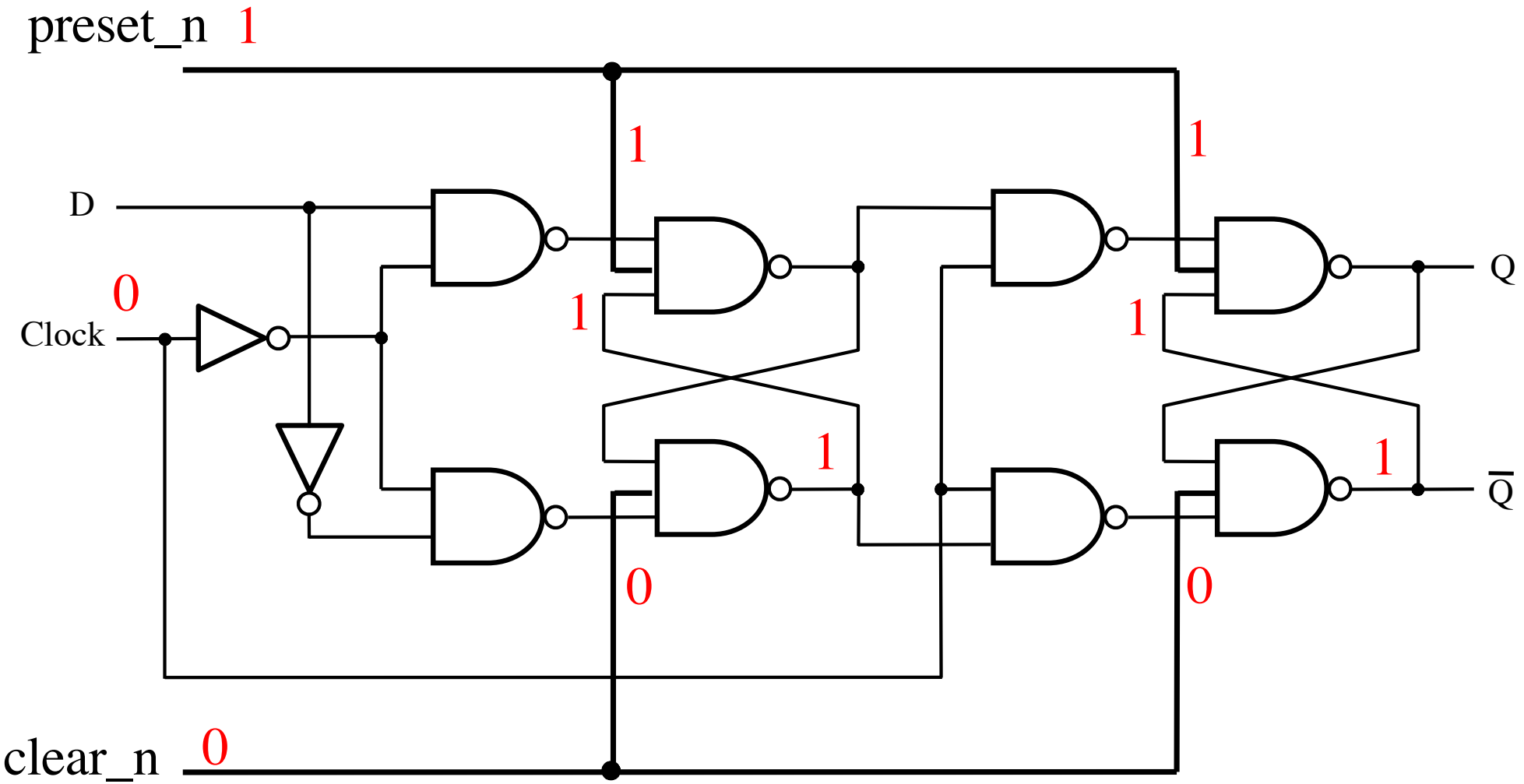
How does clear work?

Clock=1



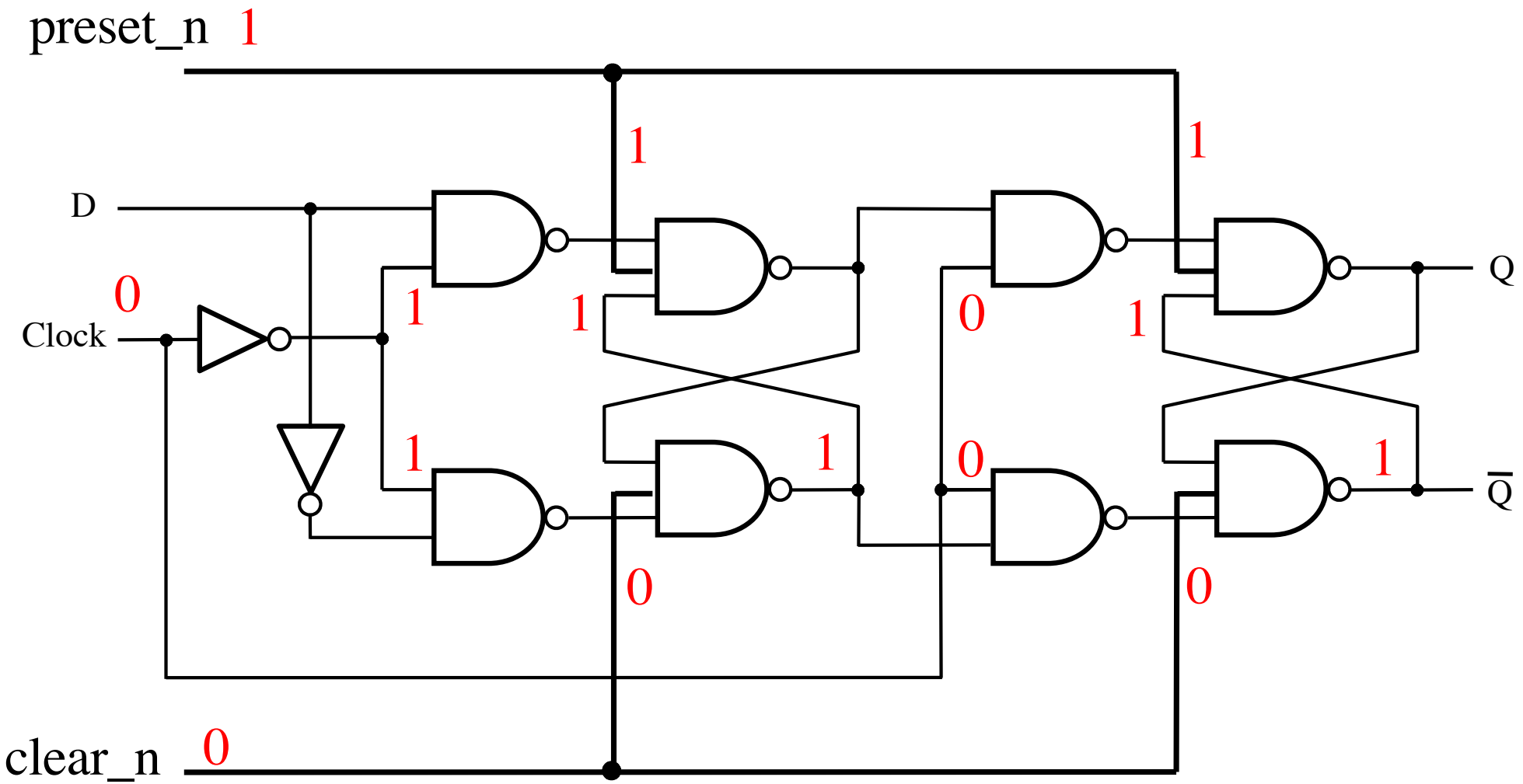
How does clear work?

Clock=0



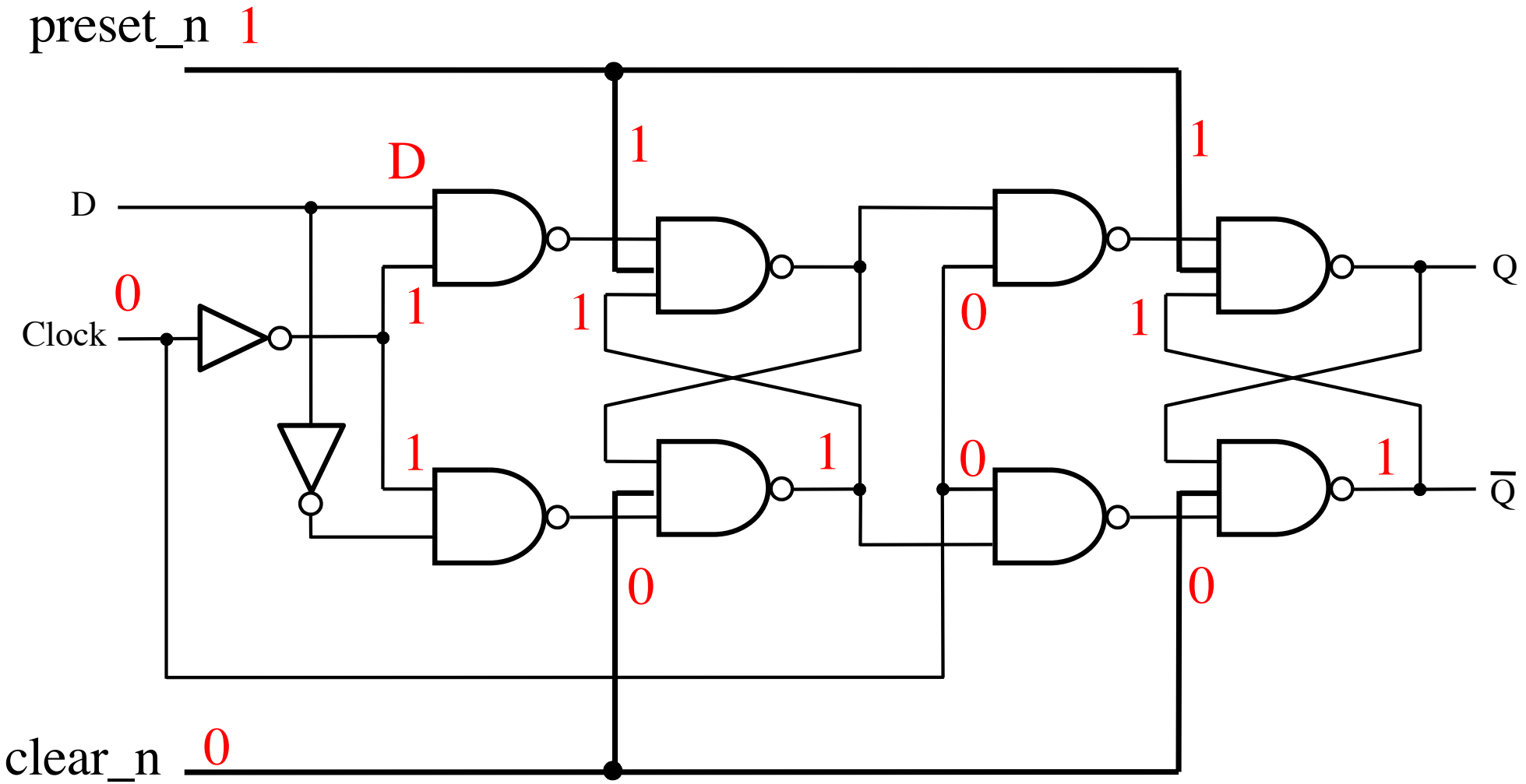
How does clear work?

Clock=0



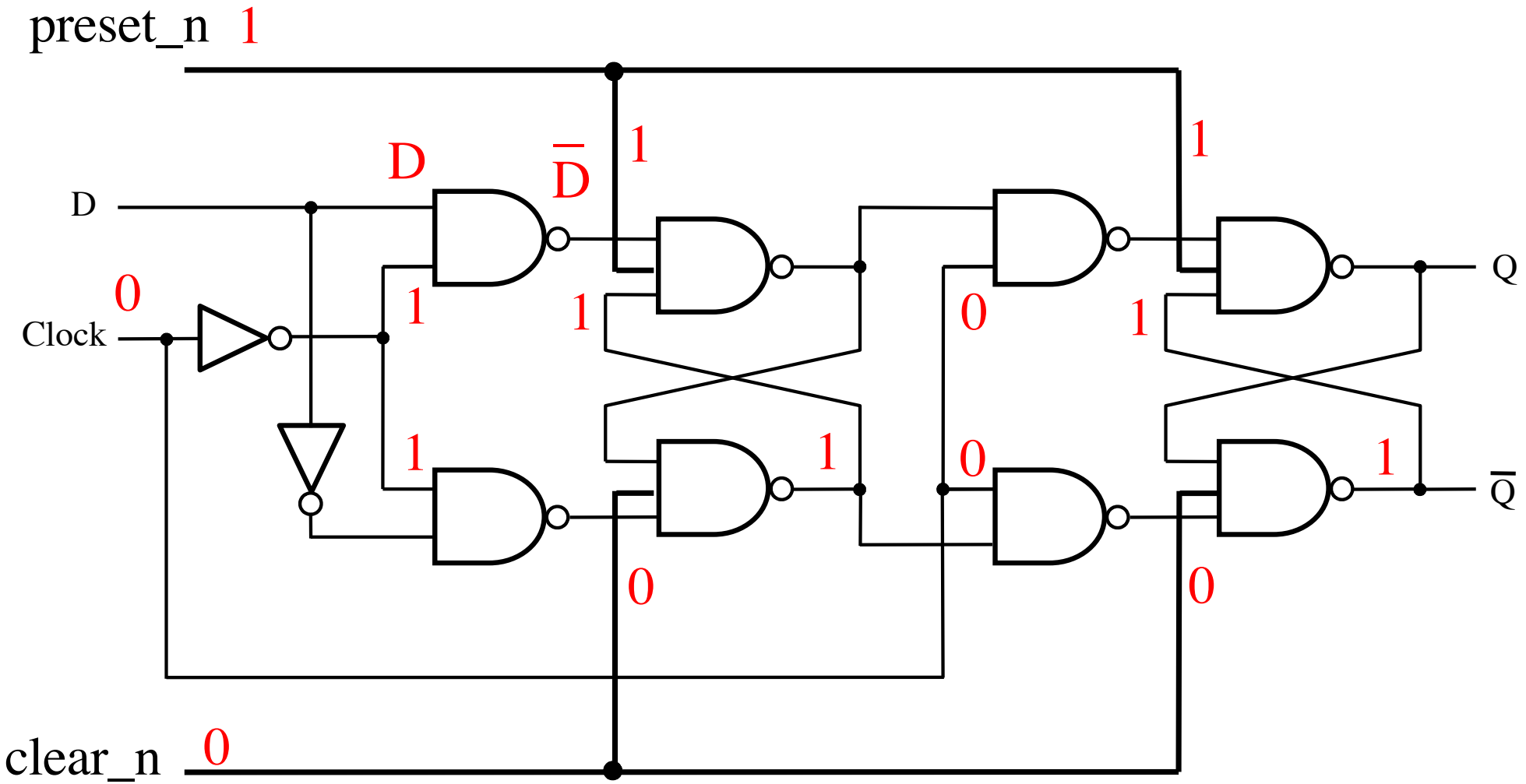
How does clear work?

Clock=0



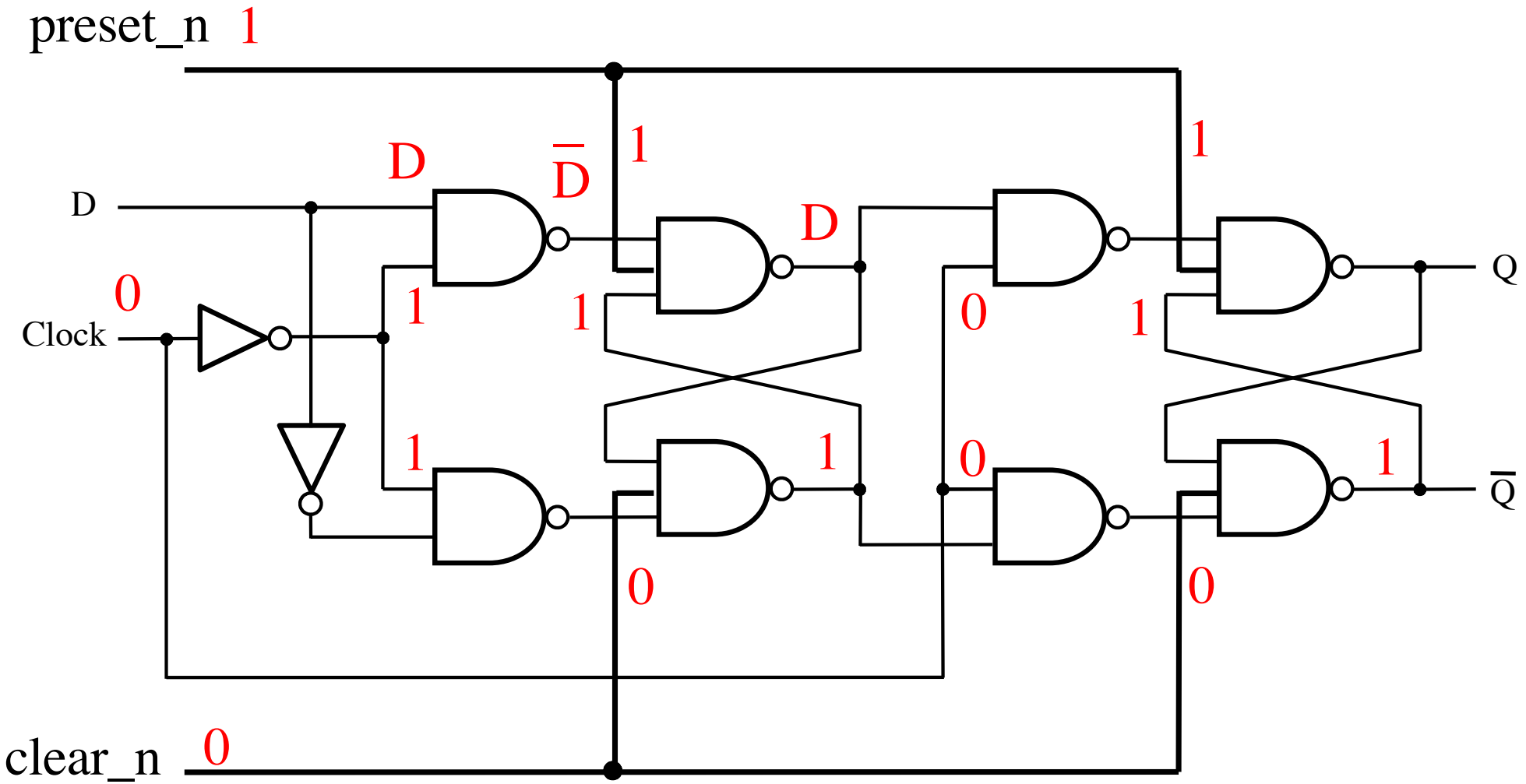
How does clear work?

Clock=0



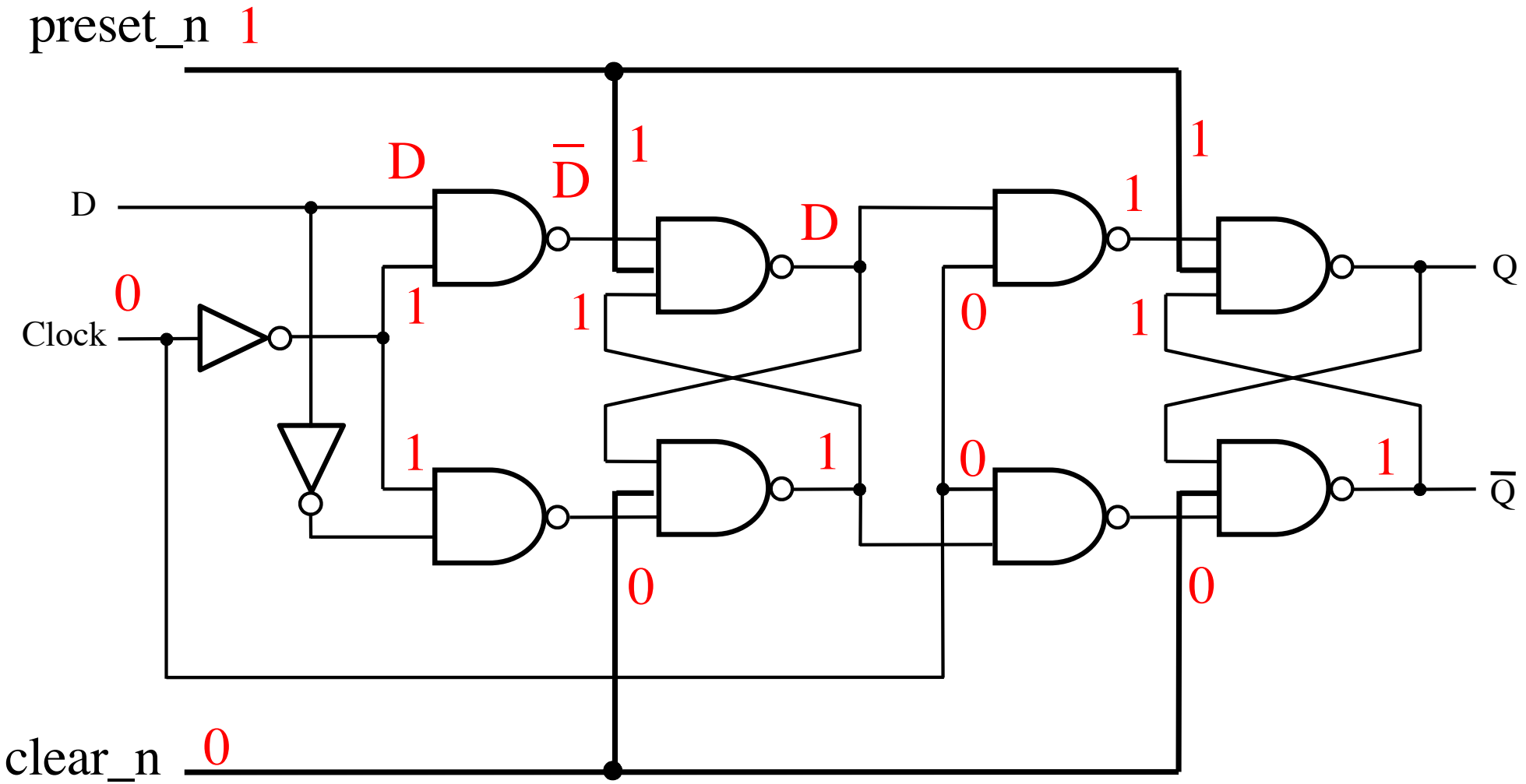
How does clear work?

Clock=0



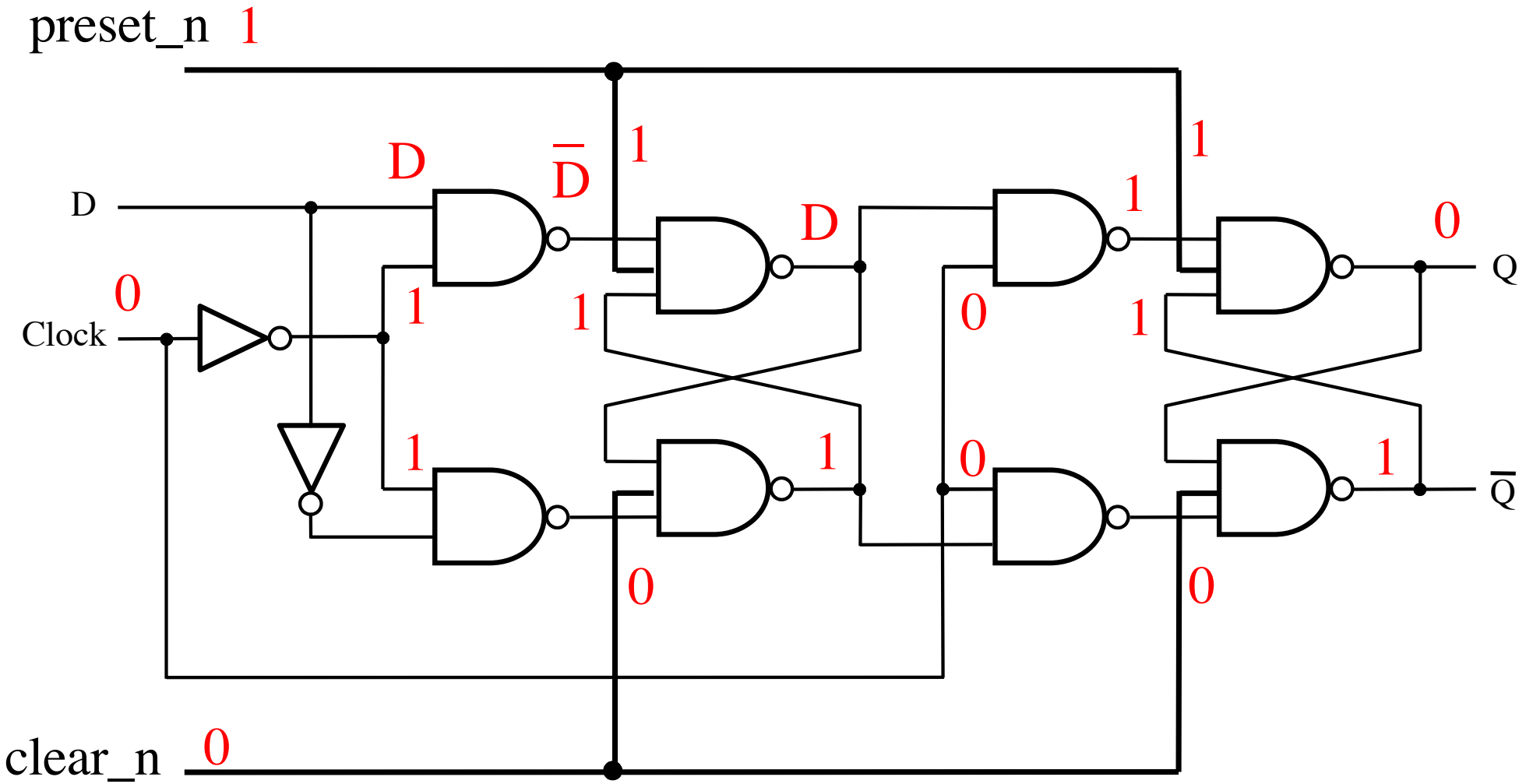
How does clear work?

Clock=0

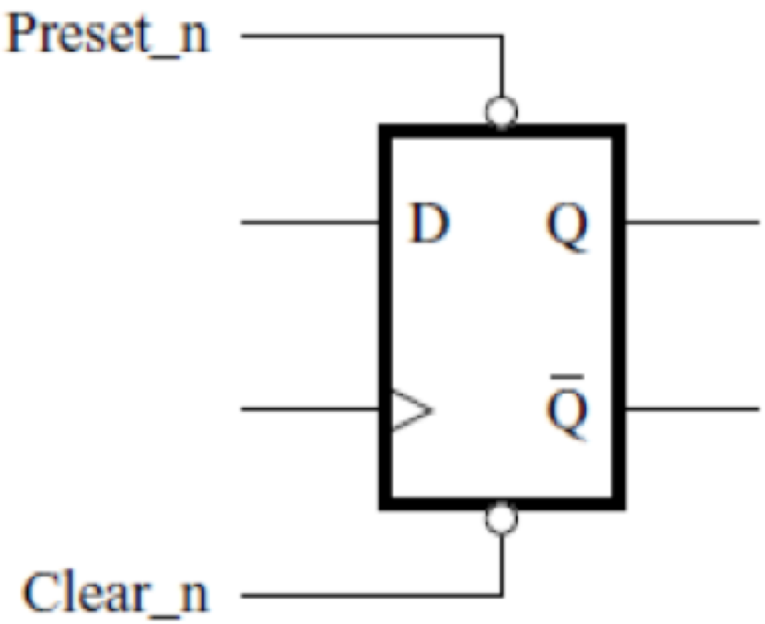


How does clear work?

Clock=0



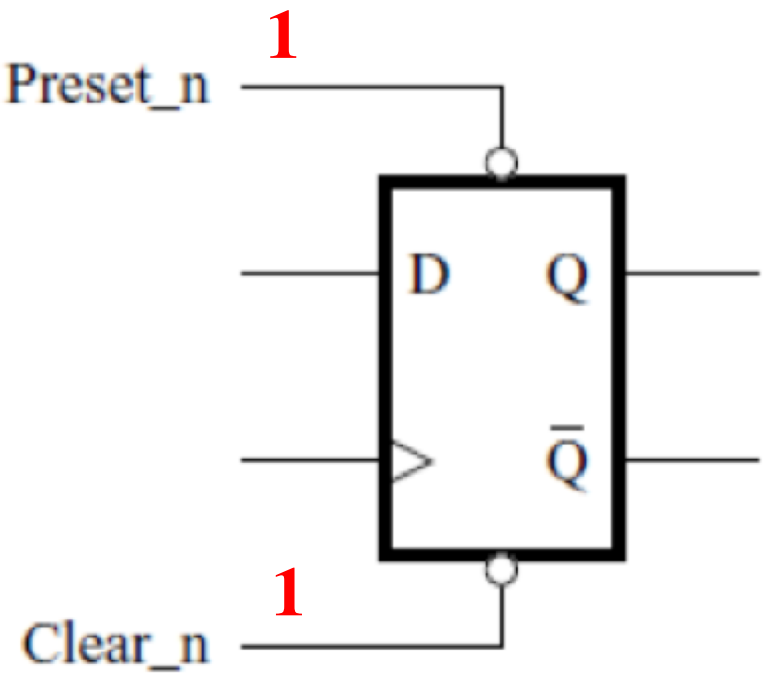
Positive-edge-triggered D flip-flop with asynchronous Clear and Preset



(b) Graphical symbol

[Figure 5.13b from the textbook]

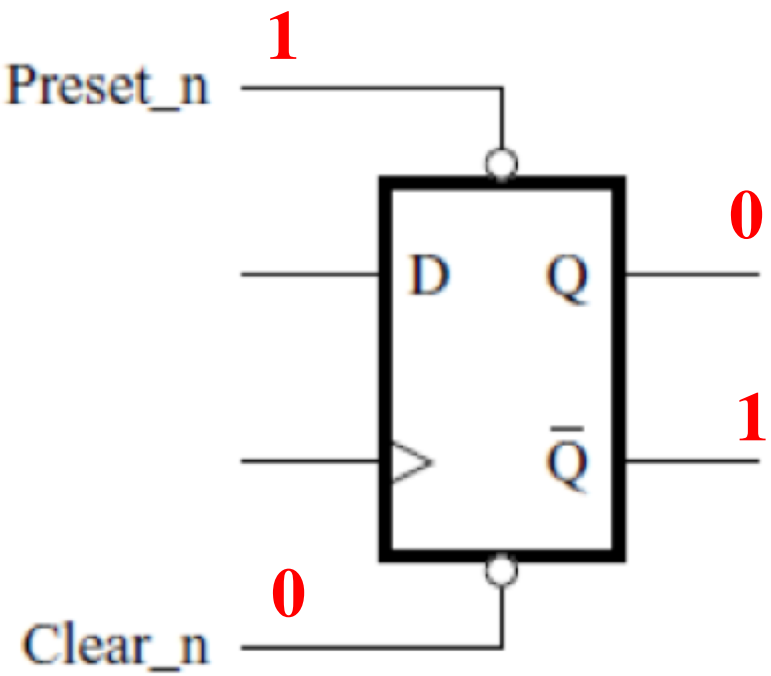
For normal operation both must be set to 1



(b) Graphical symbol

[Figure 5.13b from the textbook]

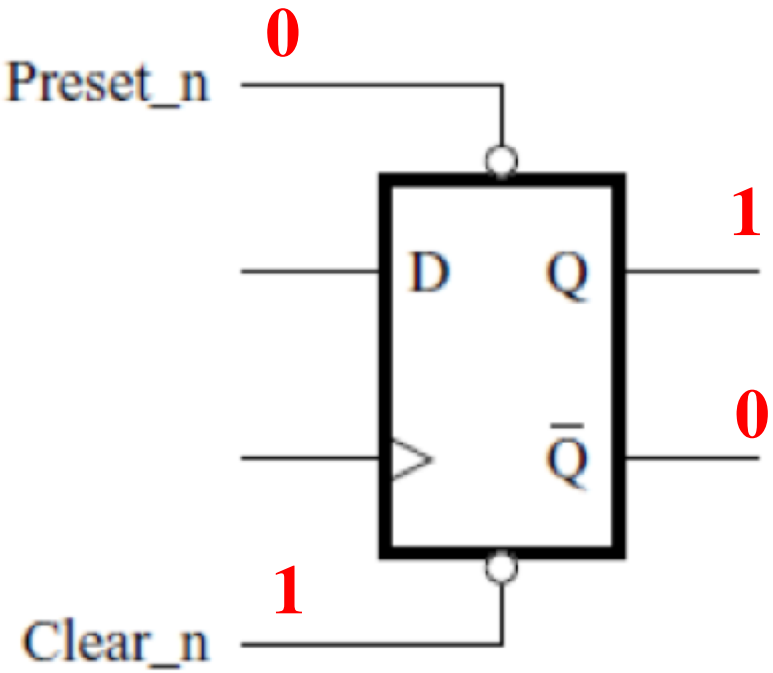
A zero on clear_n drives the output Q to zero



(b) Graphical symbol

[Figure 5.13b from the textbook]

A zero on preset_n drives the output Q to one

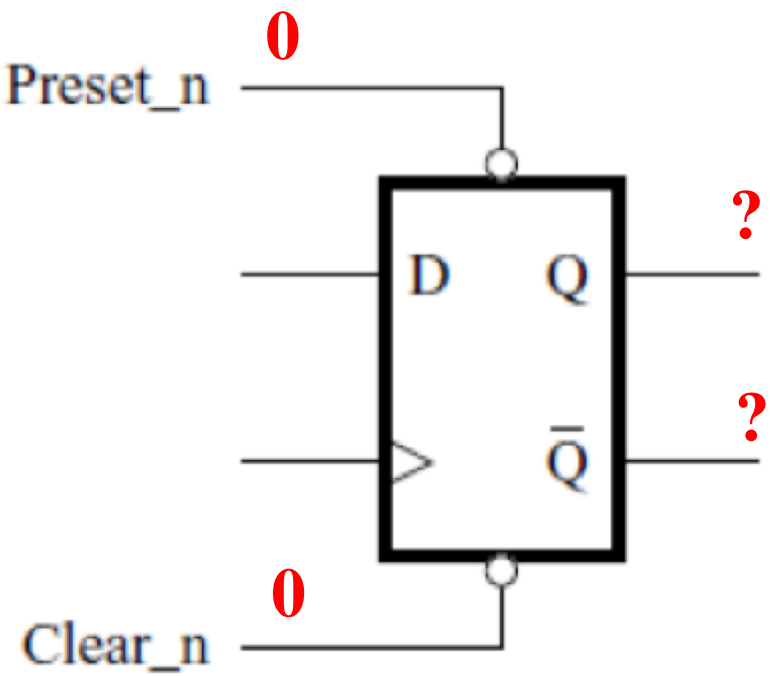


(b) Graphical symbol

[Figure 5.13b from the textbook]

The output is indeterminate if both are zero

don't ever use this one



(b) Graphical symbol

[Figure 5.13b from the textbook]

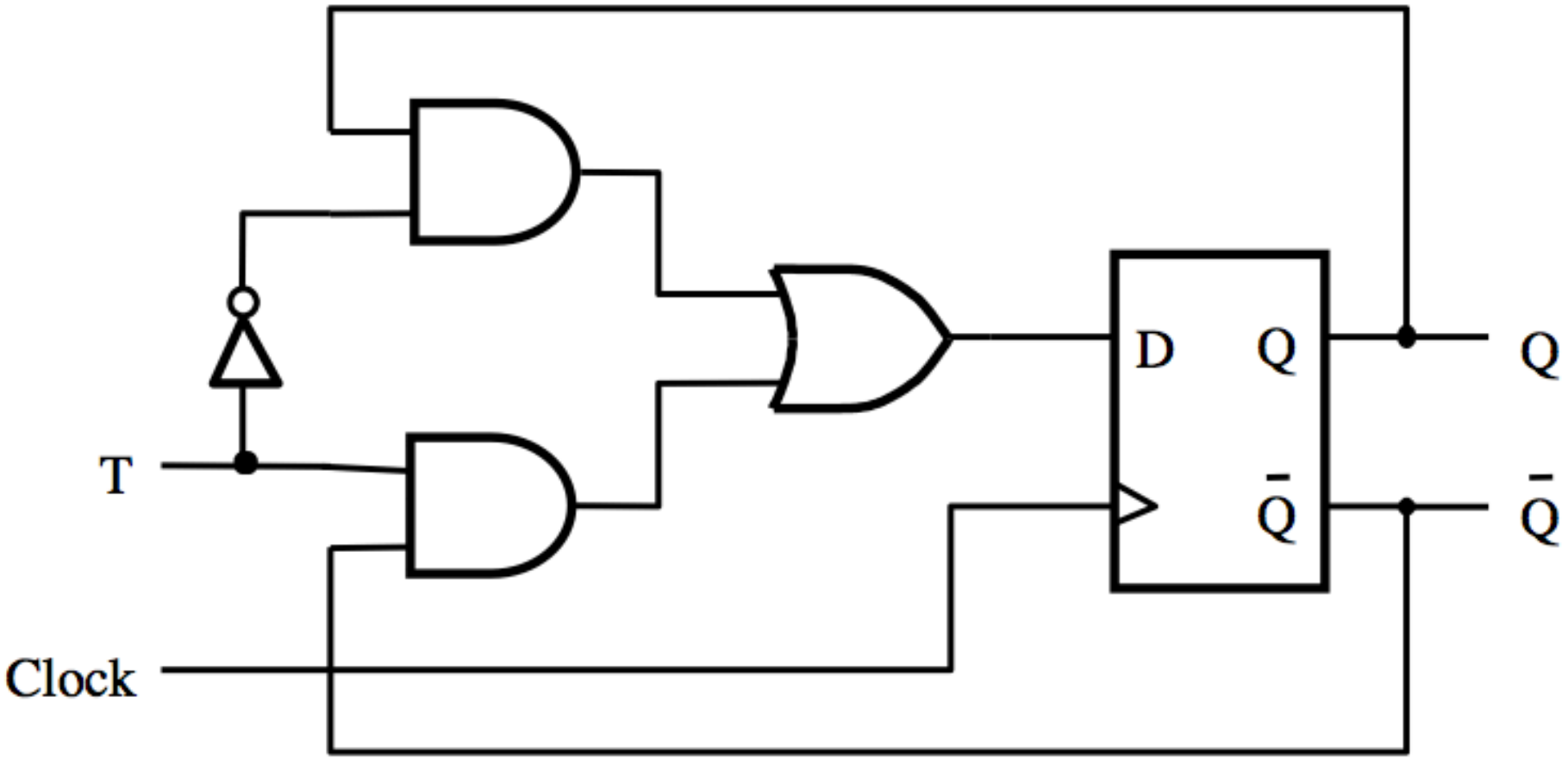
T Flip-Flop

Motivation

A slight modification of the D flip-flop that can be used for some nice applications (e.g., counters).

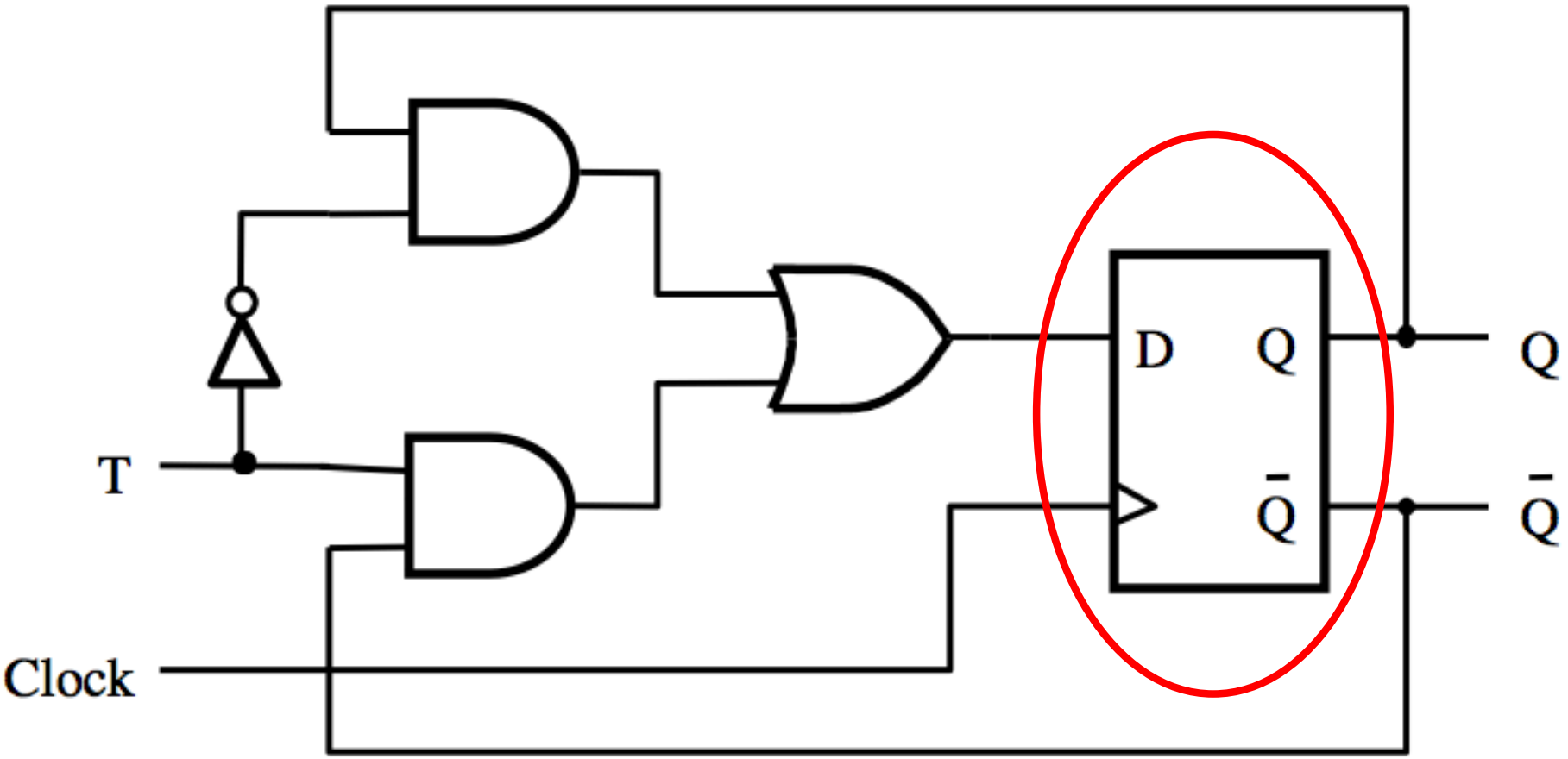
In this case, T stands for Toggle.

T Flip-Flop



[Figure 5.15a from the textbook]

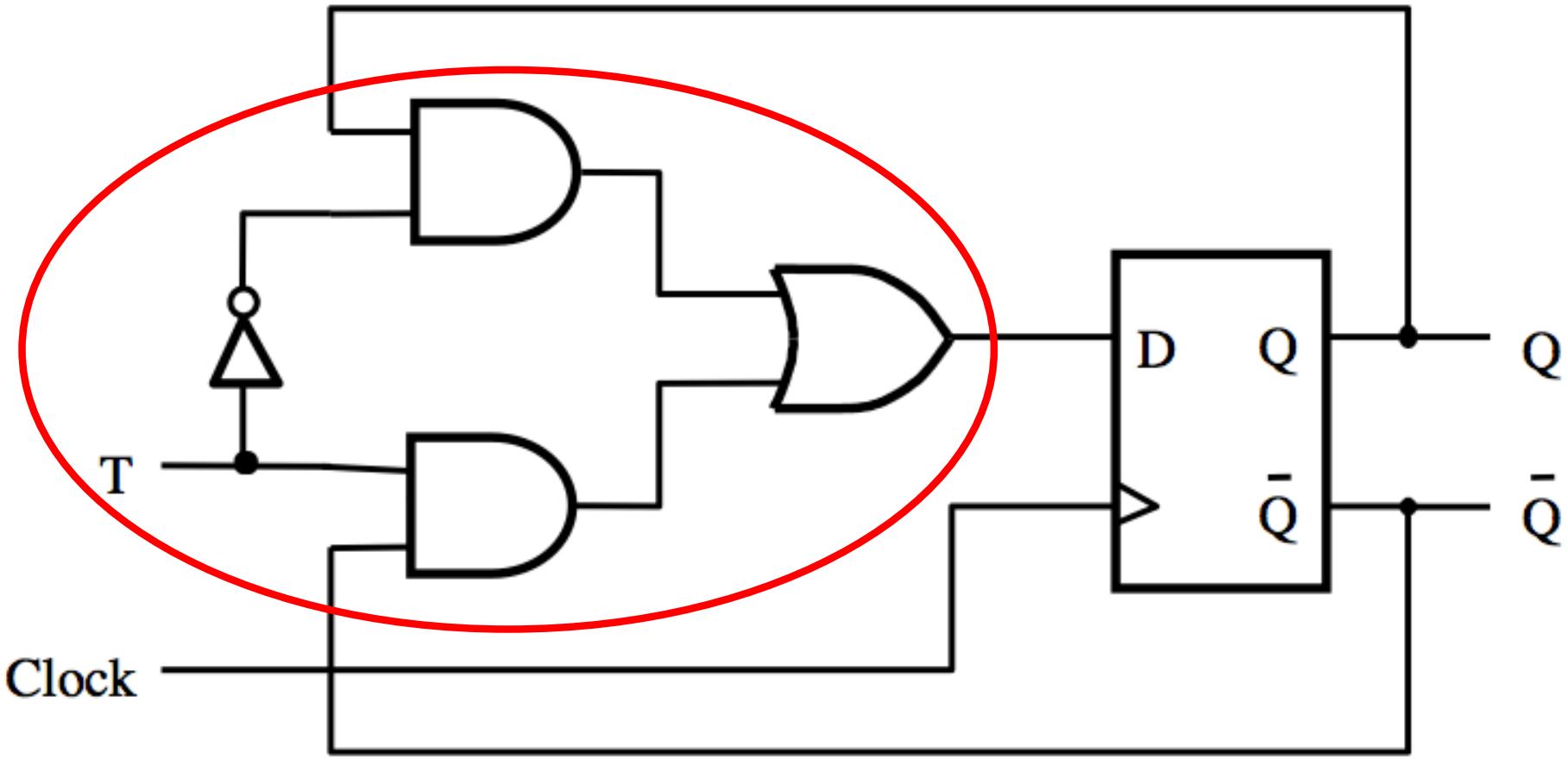
T Flip-Flop



Positive-edge-triggered
D Flip-Flop

[Figure 5.15a from the textbook]

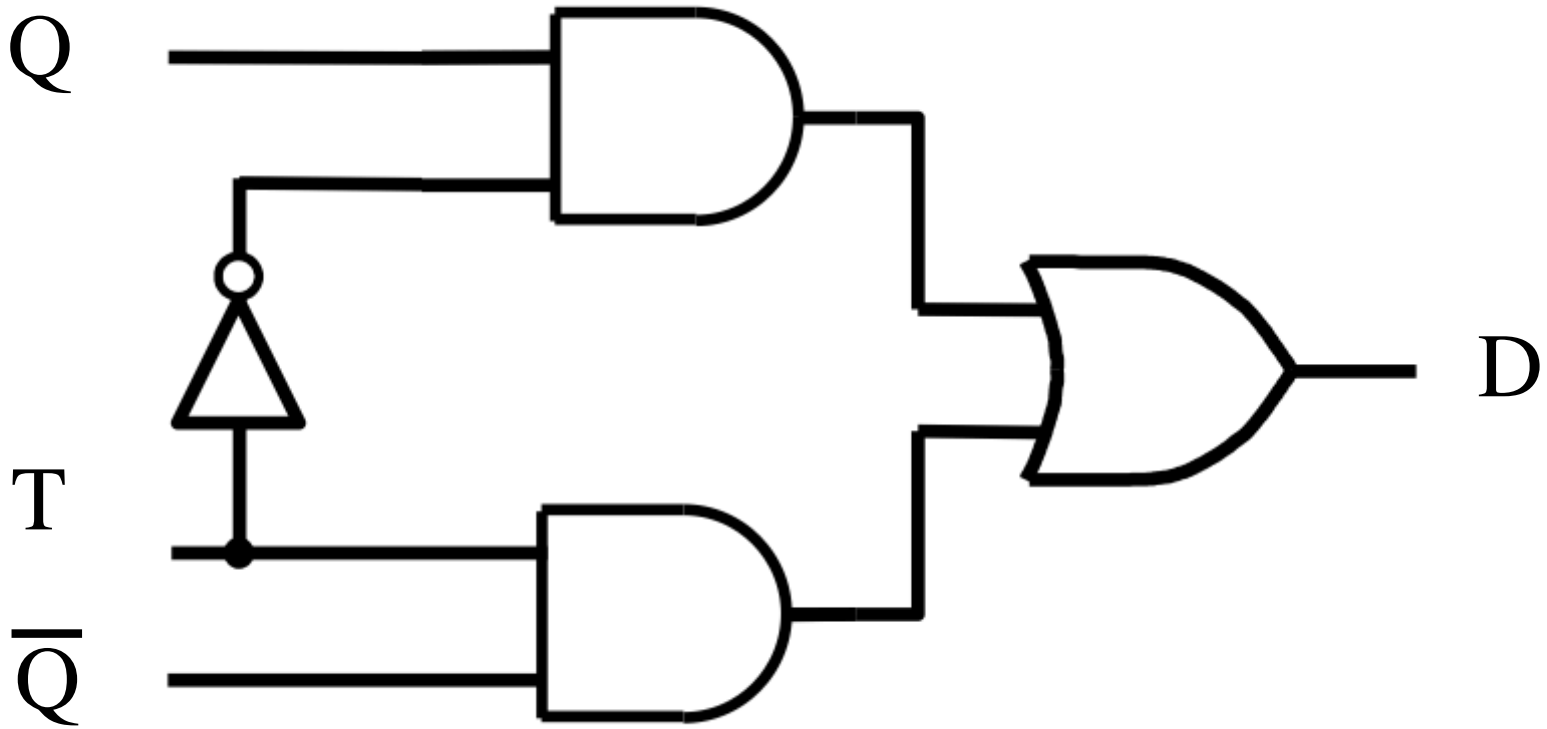
T Flip-Flop



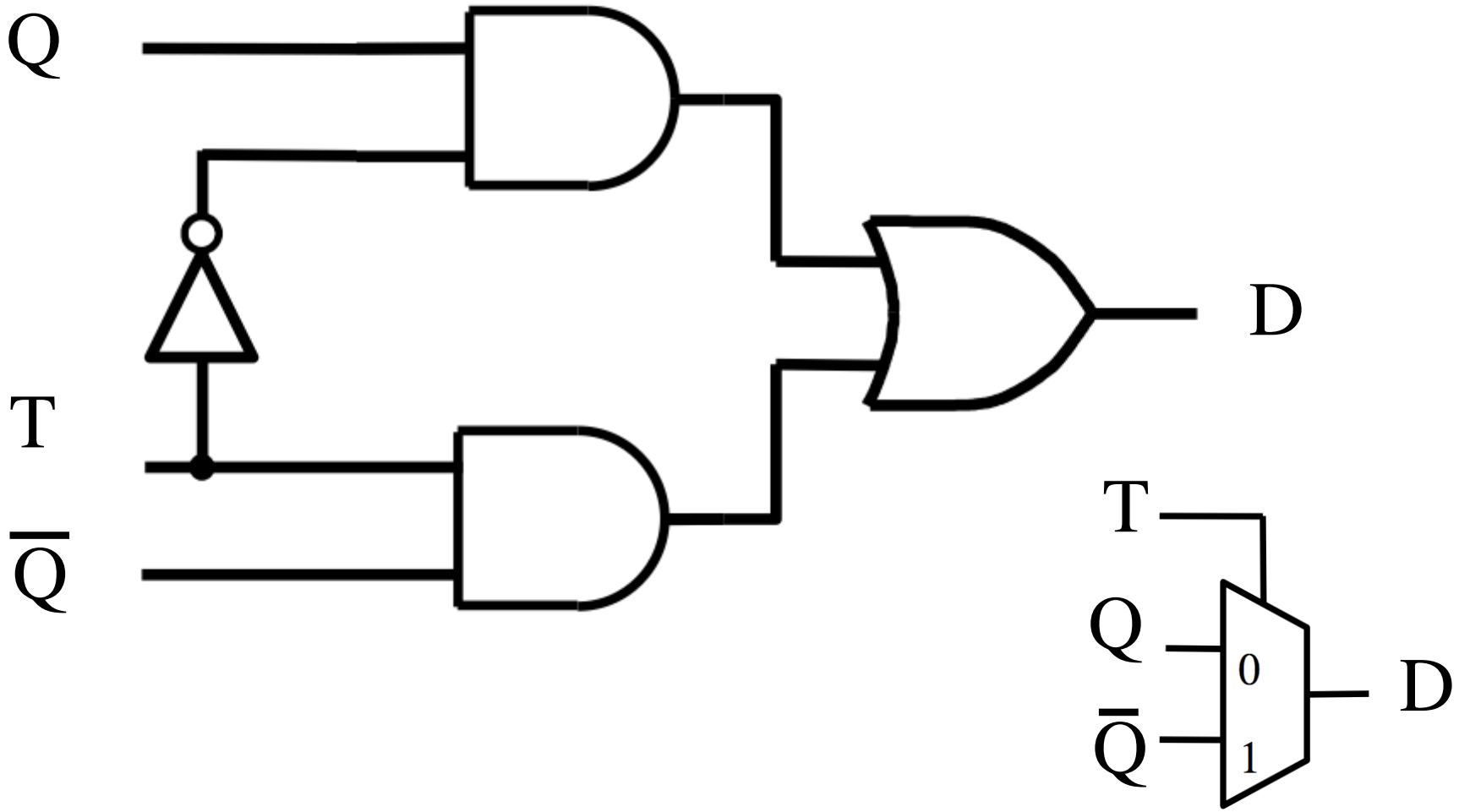
What is this?

[Figure 5.15a from the textbook]

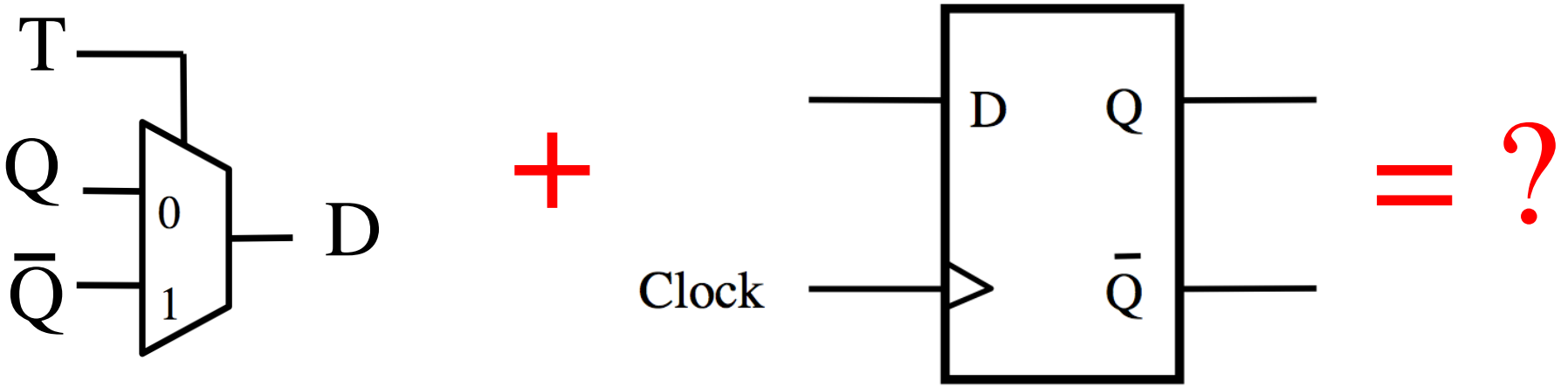
What is this?



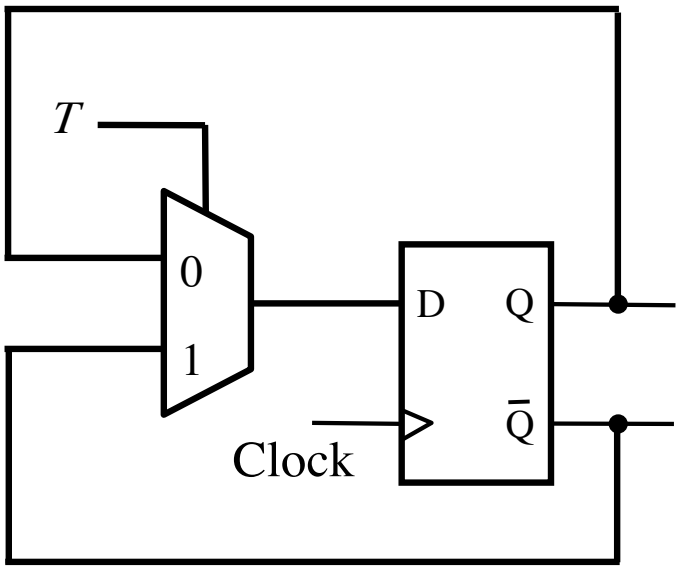
It is a 2-to-1 Multiplexer



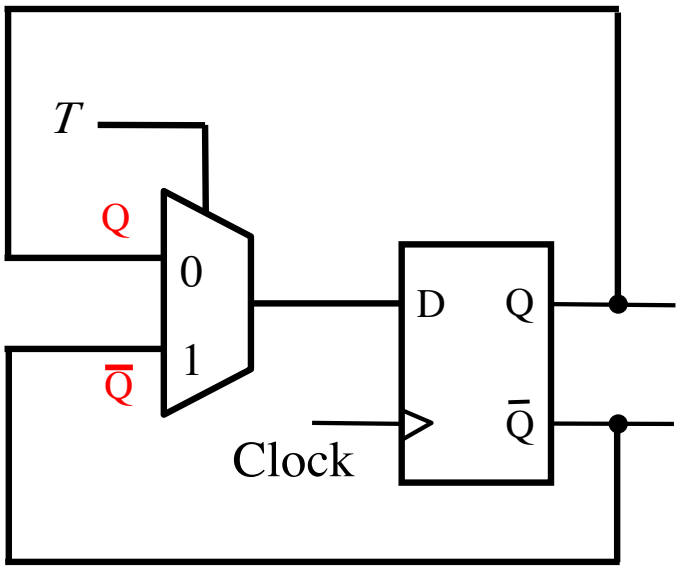
What is this?



It is a T Flip-Flop

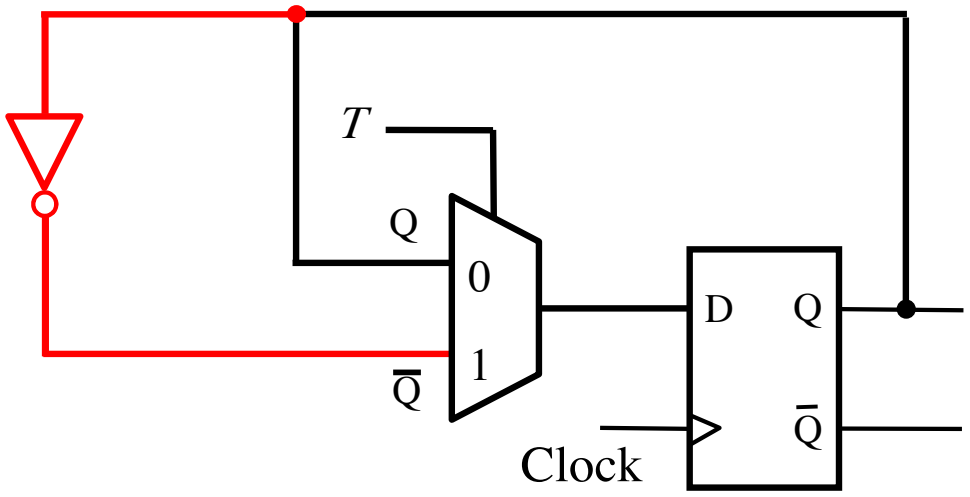


It is a T Flip-Flop

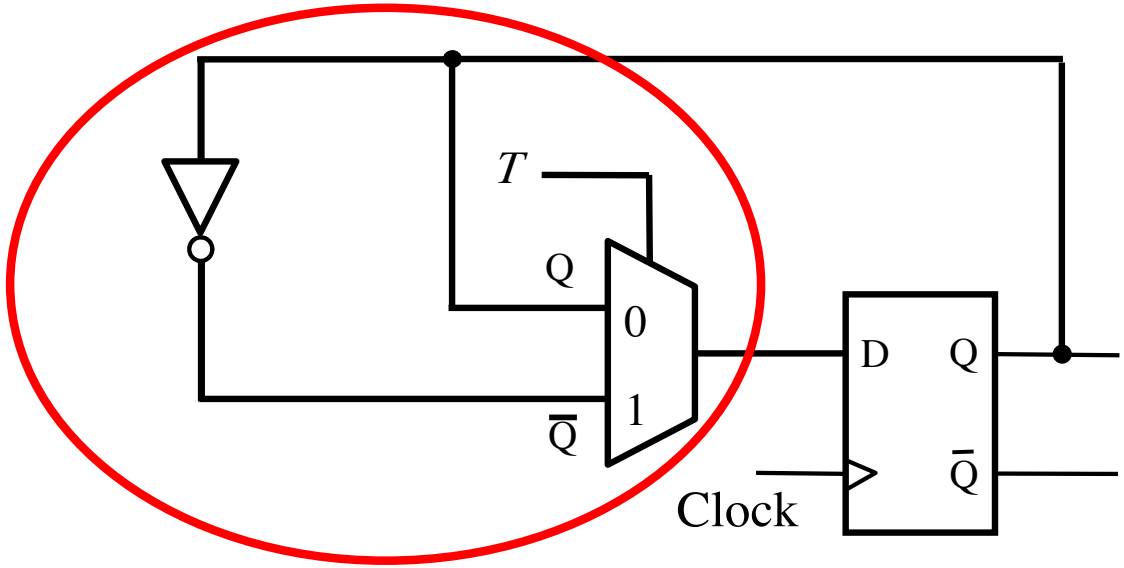


Note that the two inputs to the multiplexer are inverses of each other.

Another Way to Draw This

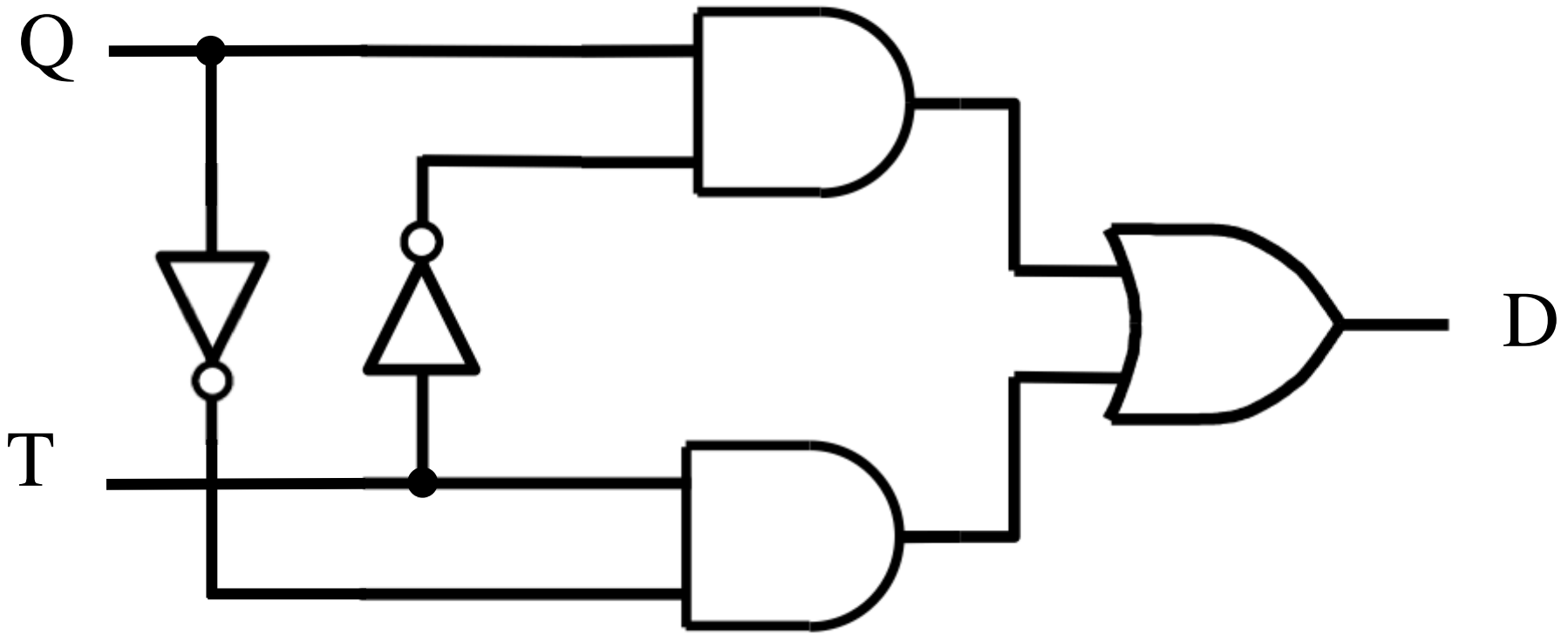


Another Way to Draw This

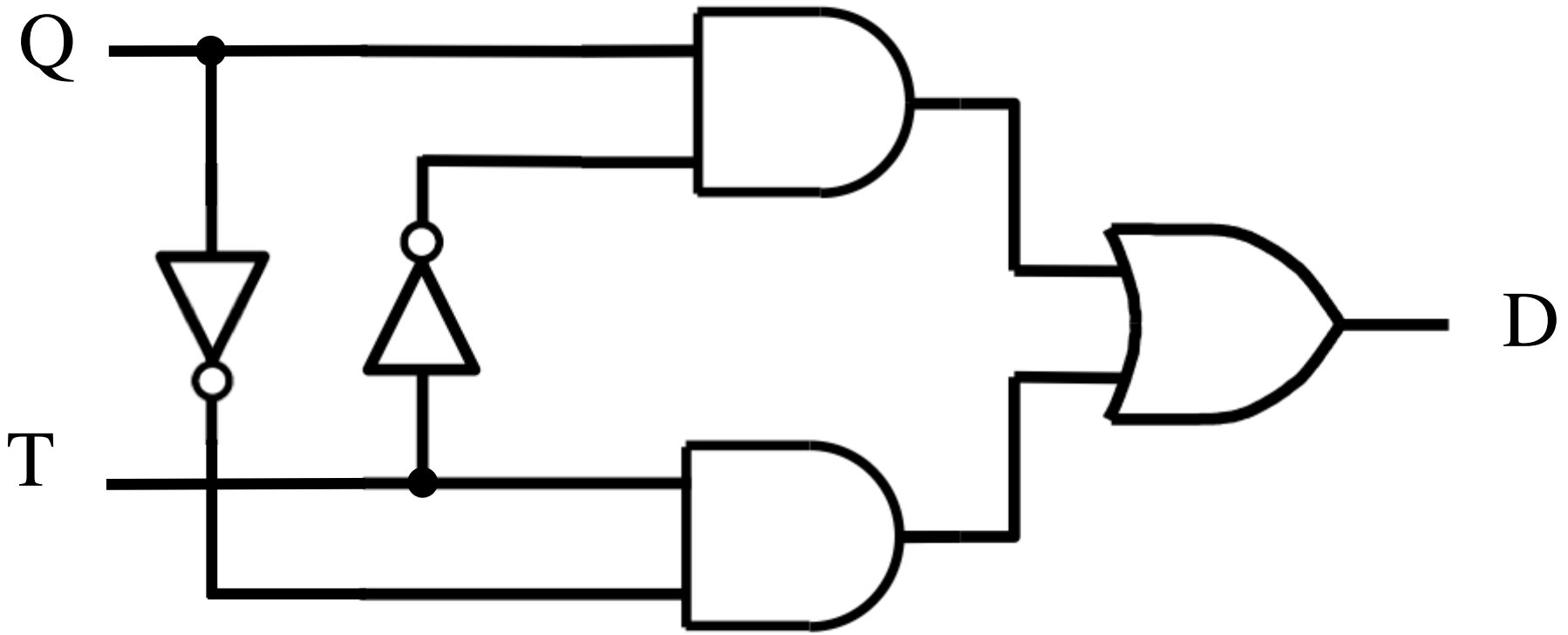


What is this?

What is this?

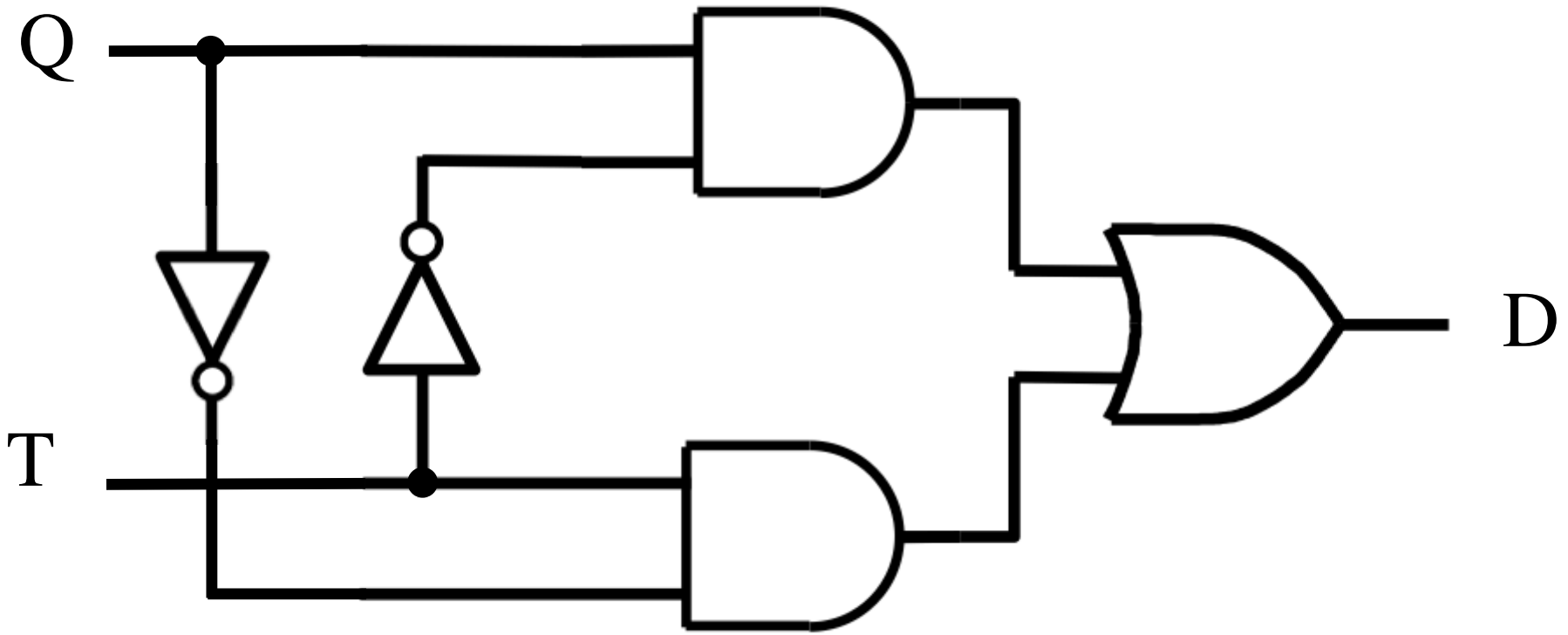


What is this?



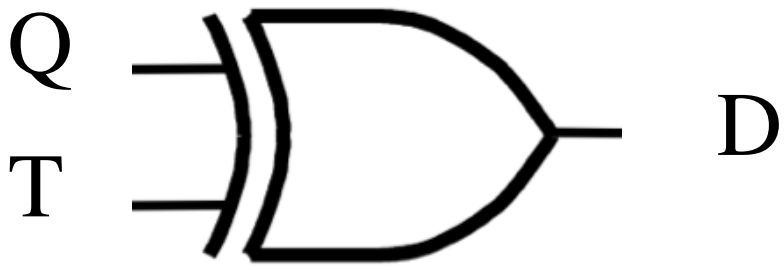
$$D = Q\overline{T} + \overline{Q}T$$

It is an XOR



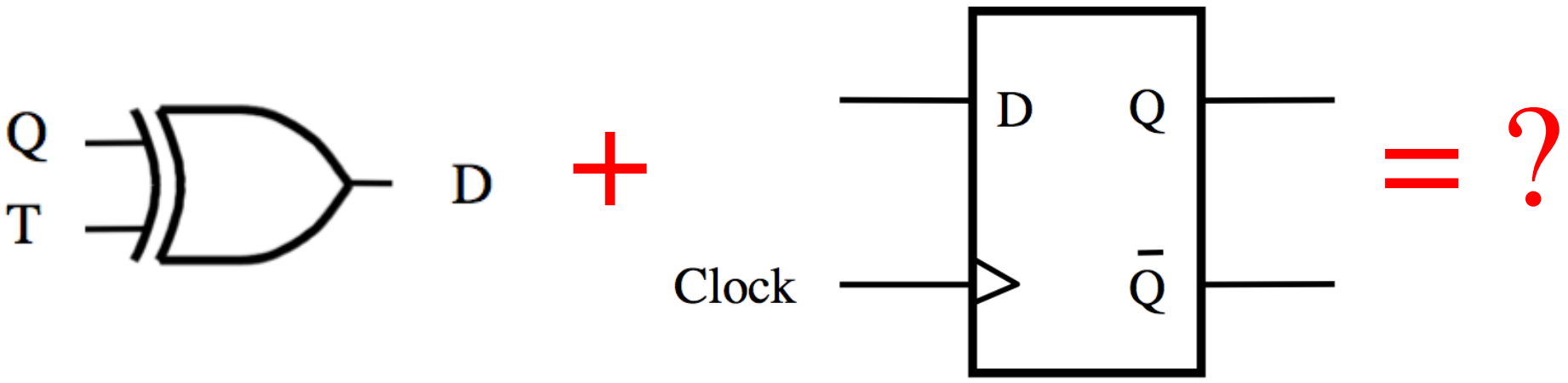
$$D = Q \oplus T$$

It is an XOR

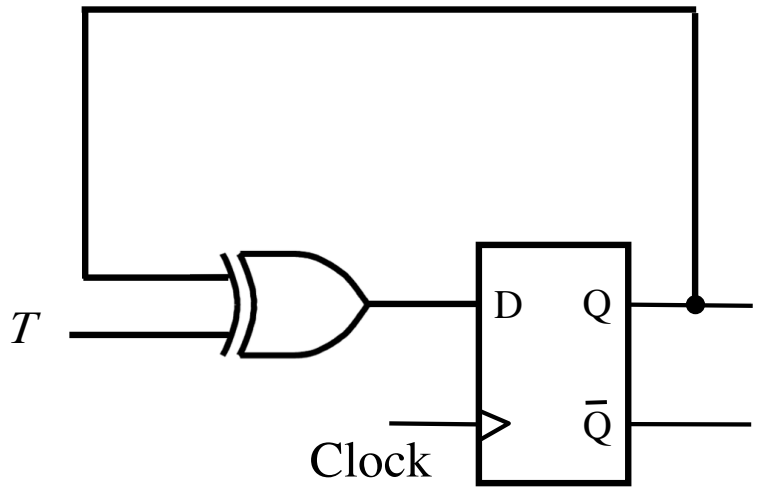


$$D = Q \oplus T$$

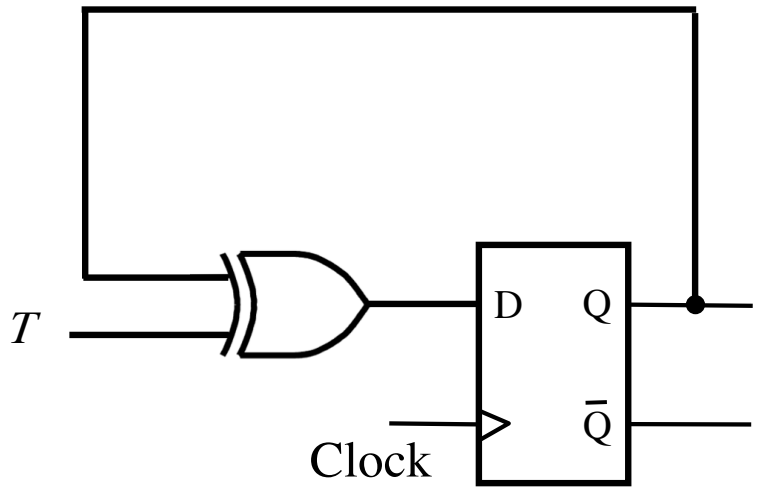
What is this?



It is a T Flip-Flop too

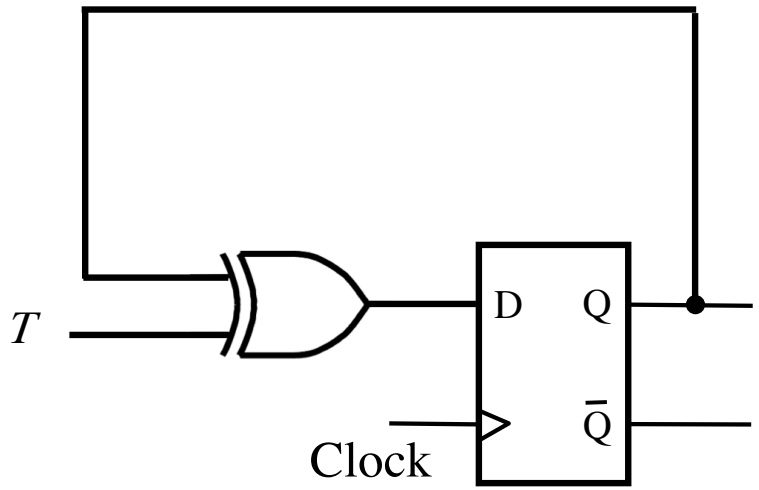


It is a T Flip-Flop too



T	Q	D
0	0	0
0	1	1
1	0	1
1	1	0

It is a T Flip-Flop too



T	Q	D	
0	0	0	Q
0	1	1	
1	0	1	Q̄
1	1	0	

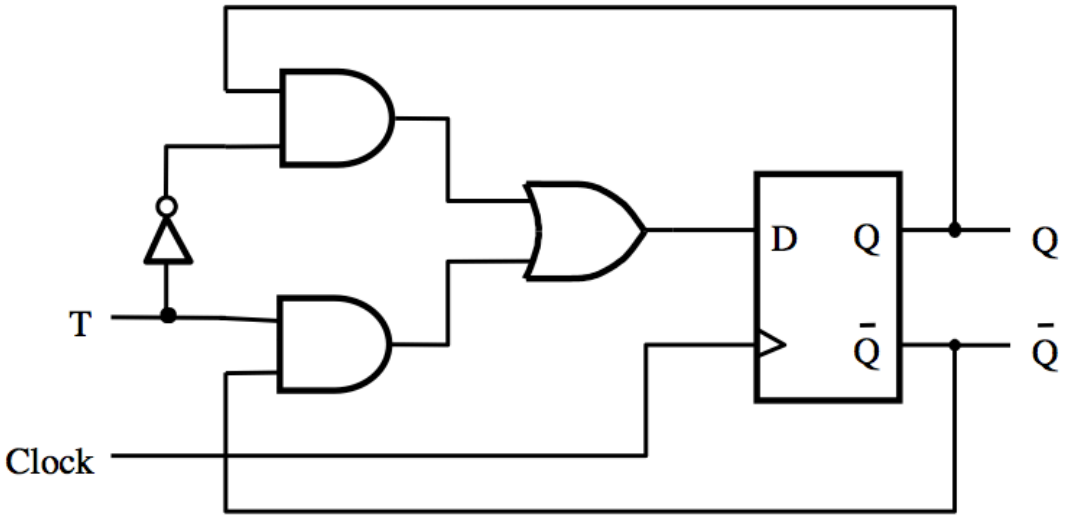
T Flip-Flop
(how it works)

If T=0 then it stays in its current state

If T=1 then it reverses its current state

In other words the circuit “toggles” its state when T=1. This is why it is called T flip-flop.

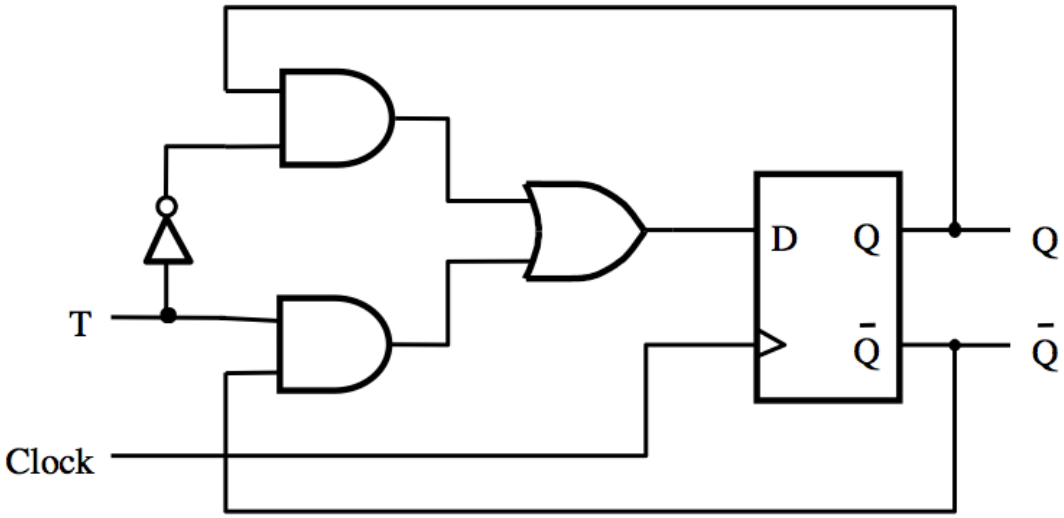
T Flip-Flop
(circuit and truth table)

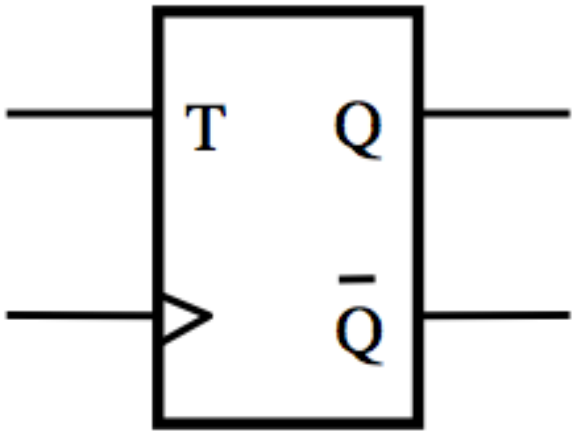


T	$Q(t+1)$
0	$Q(t)$
1	$\overline{Q}(t)$

[Figure 5.15a,b from the textbook]

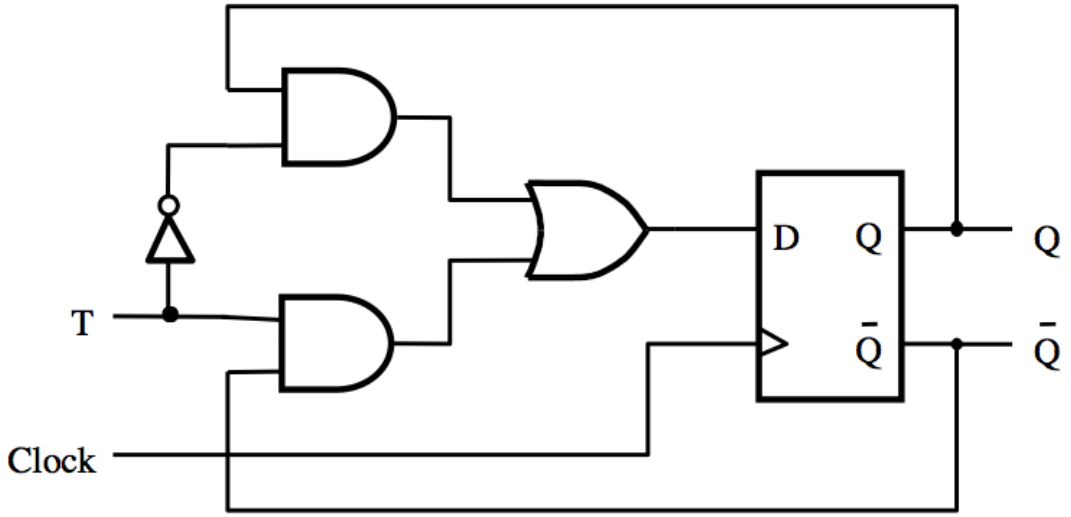
T Flip-Flop
(circuit and graphical symbol)





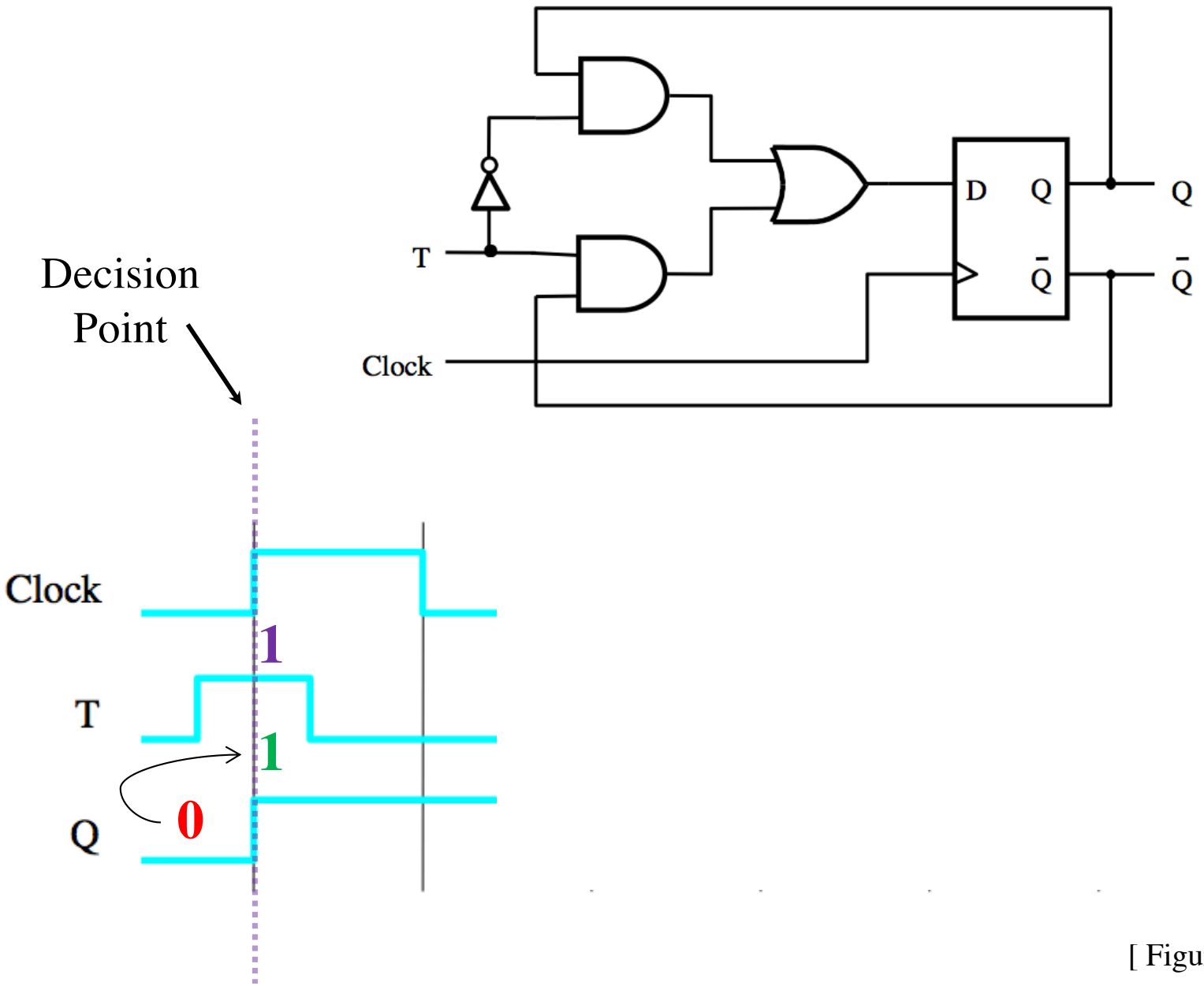
[Figure 5.15a,c from the textbook]

T Flip-Flop (Timing Diagram)



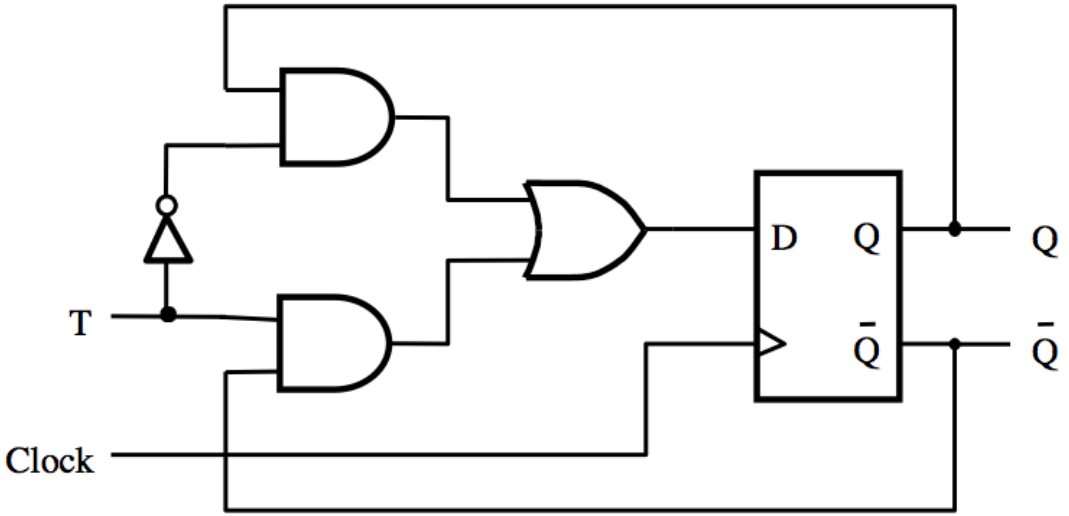
[Figure 5.15d from the textbook]

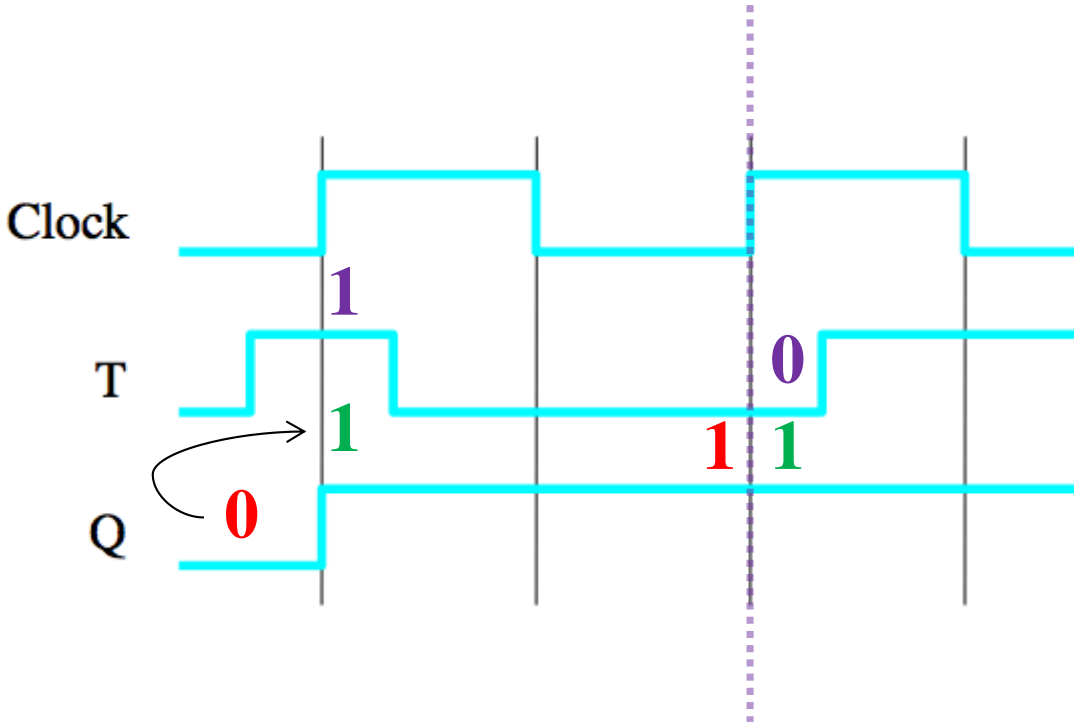
T Flip-Flop (Timing Diagram)



[Figure 5.15d from the textbook]

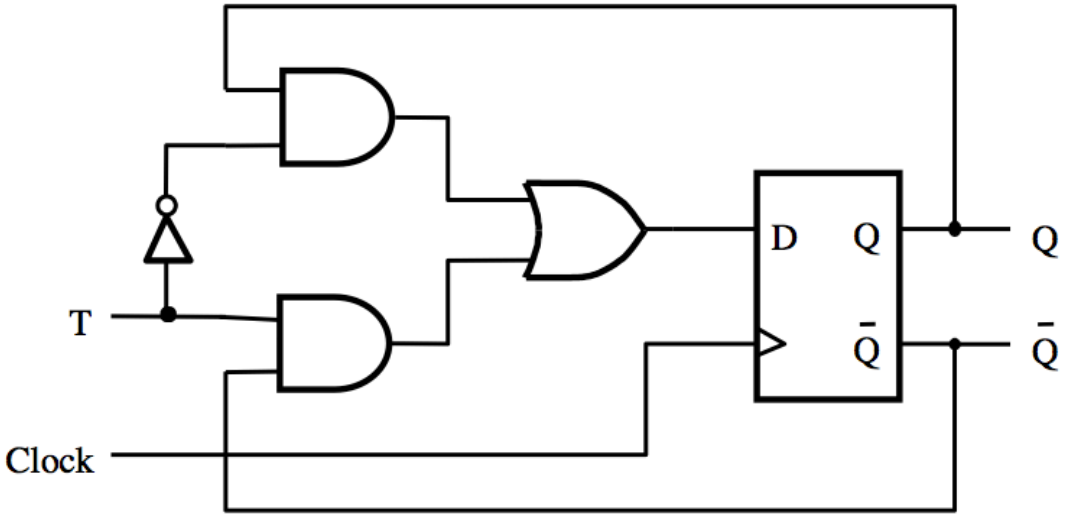
T Flip-Flop (Timing Diagram)

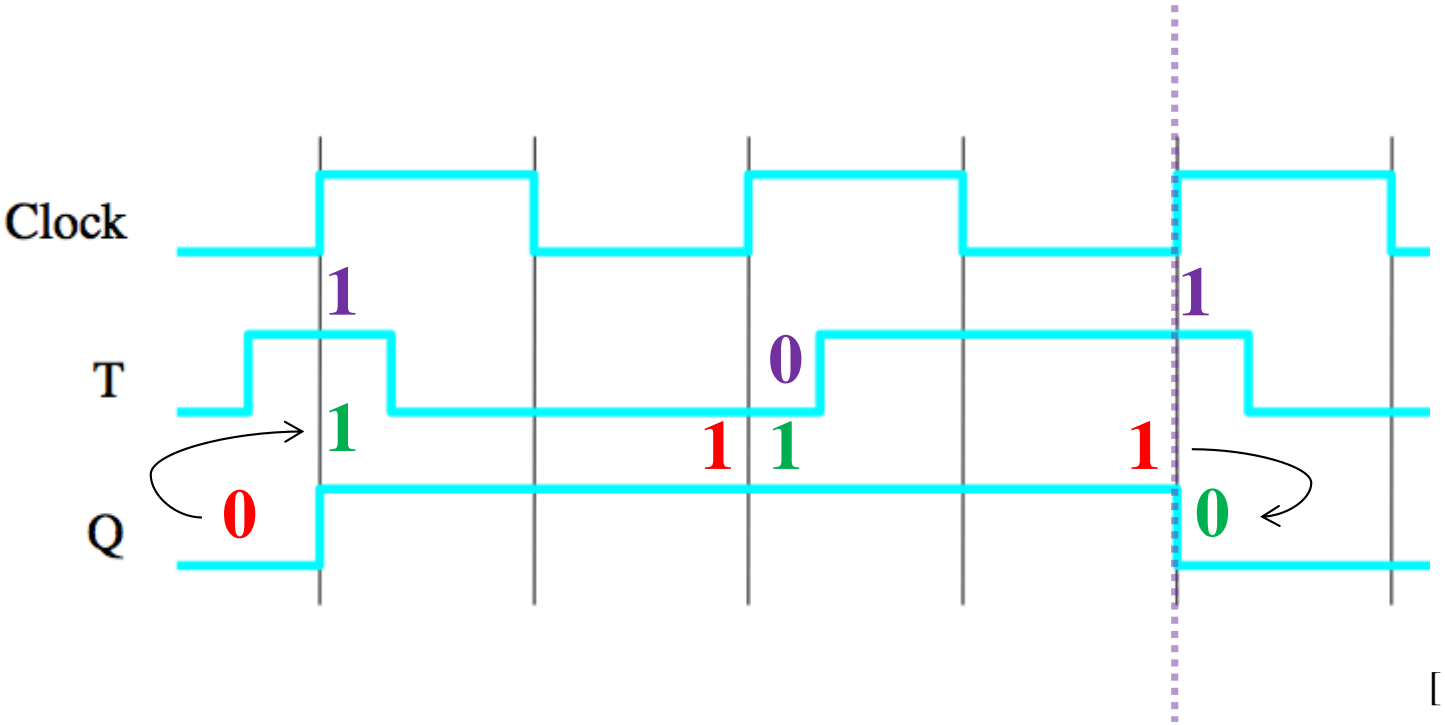




[Figure 5.15d from the textbook]

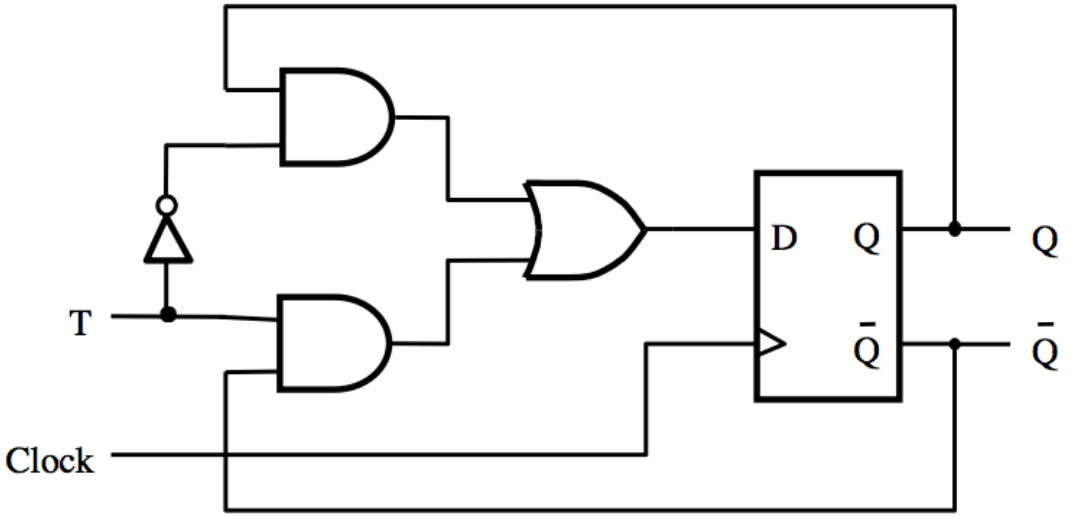
T Flip-Flop (Timing Diagram)

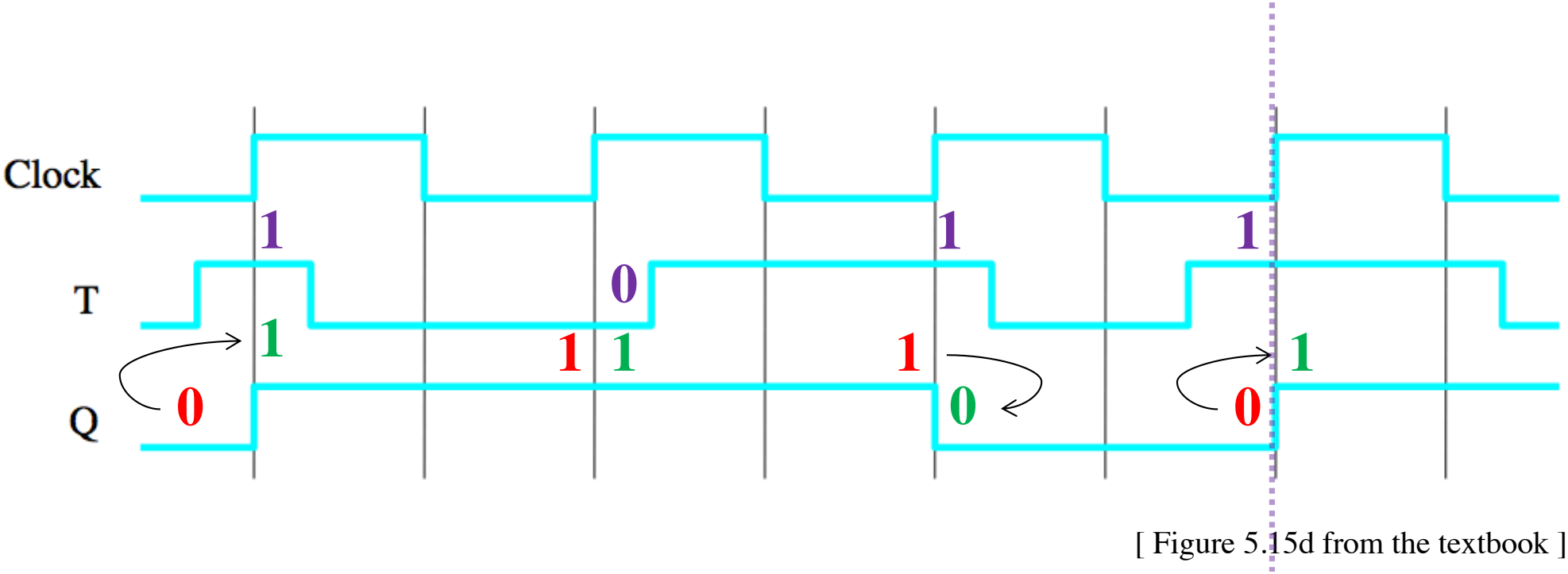




[Figure 5.15d from the textbook]

T Flip-Flop (Timing Diagram)

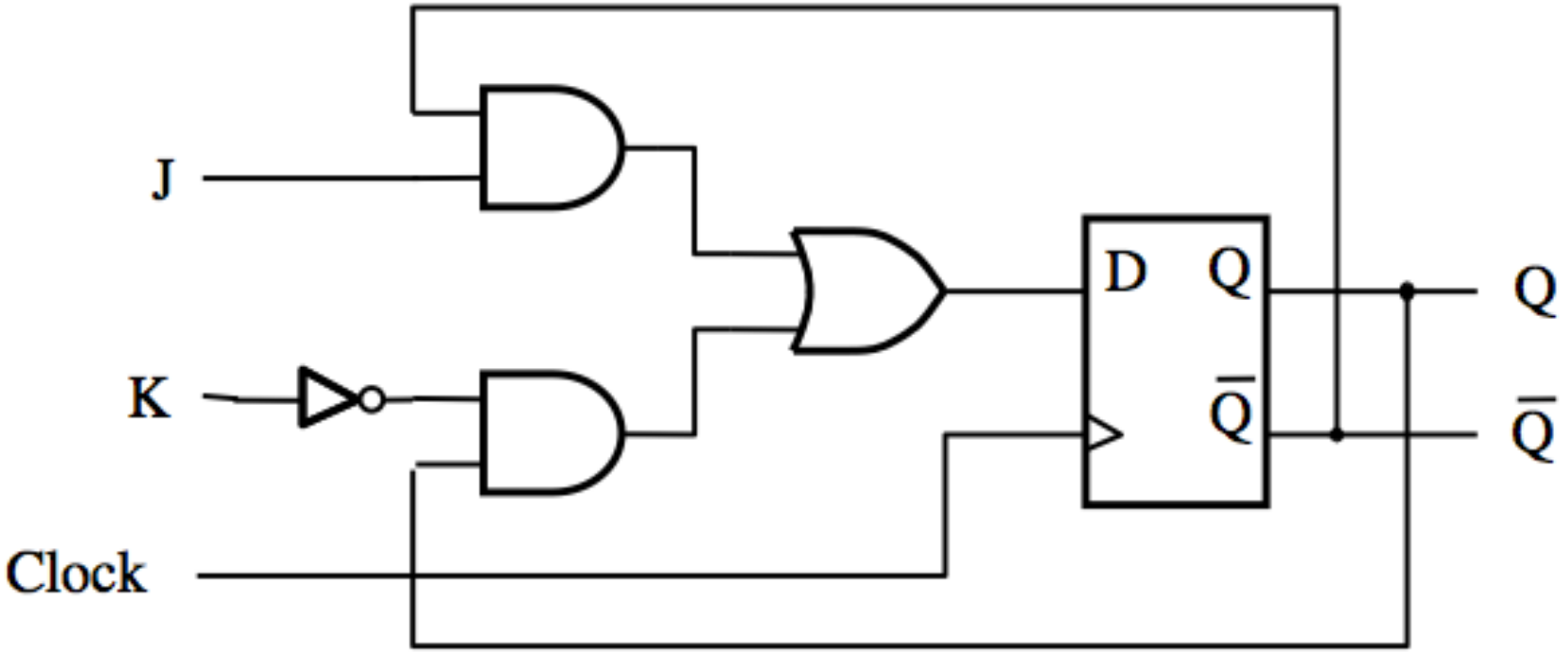




[Figure 5.15d from the textbook]

JK Flip-Flop

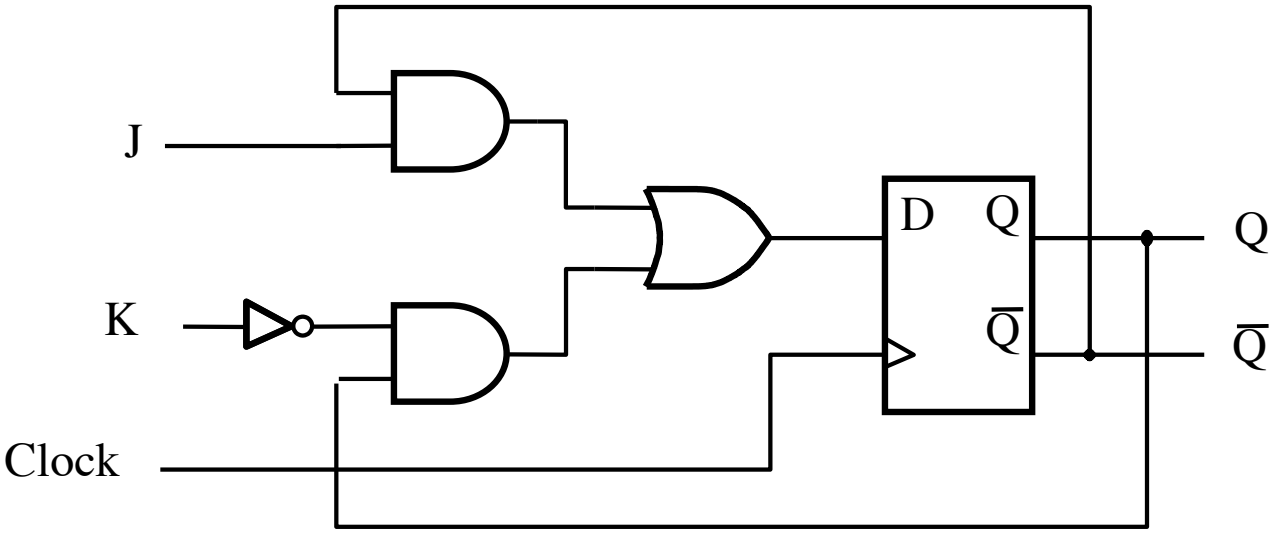
JK Flip-Flop



$$D = J\overline{Q} + \overline{K}Q$$

[Figure 5.16a from the textbook]

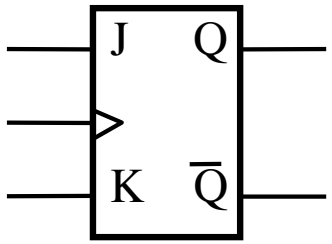
JK Flip-Flop



(a) Circuit

J	K	Q(t+1)	
0	0	Q(t)	Hold
0	1	0	Reset
1	0	1	Set
1	1	$\overline{Q}(t)$	Toggle

(b) Truth table



(c) Graphical symbol

[Figure 5.16 from the textbook]

JK Flip-Flop
(how it works)

A more versatile flip-flop

If J=0 and K=0 it stays in the same state

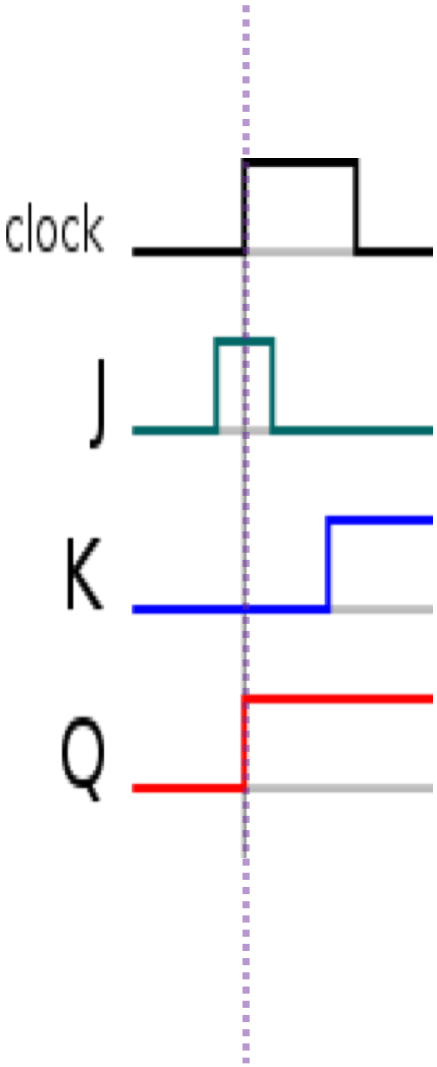
If J=1 and K=0 it sets the output Q to 1

If J=0 and K=1 it resets the output Q to 0

If J=1 and K=1 it toggles the output Q

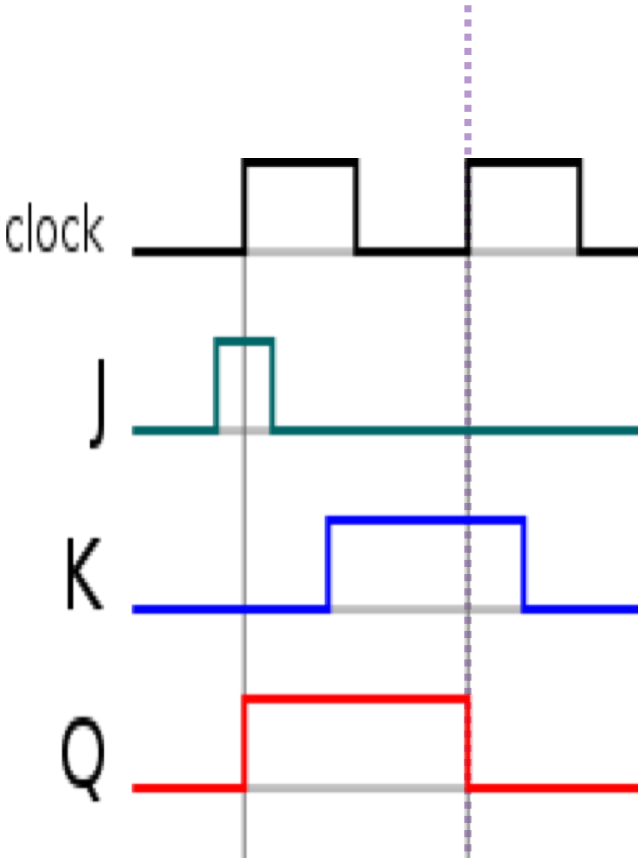
If J=K then it behaves like a T flip-flop

JK Flip-Flop
(timing diagram)



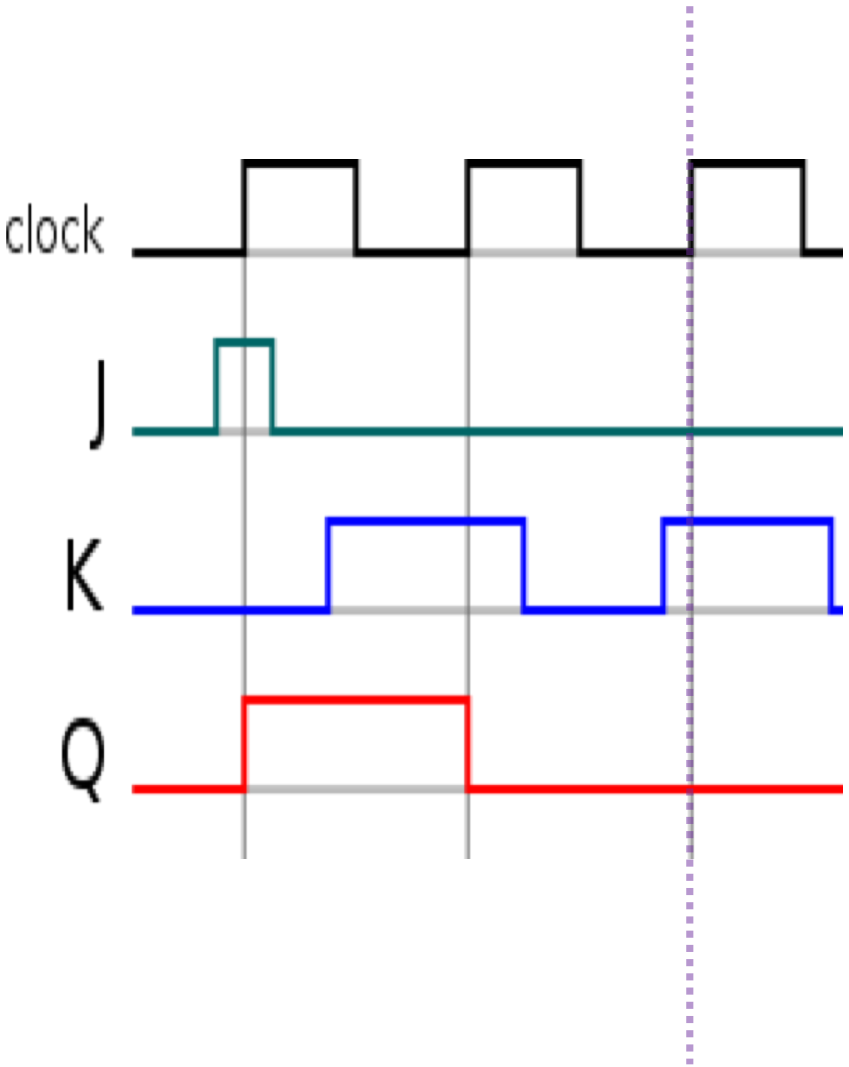
J	K	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	$\overline{Q}$(t)

JK Flip-Flop
(timing diagram)



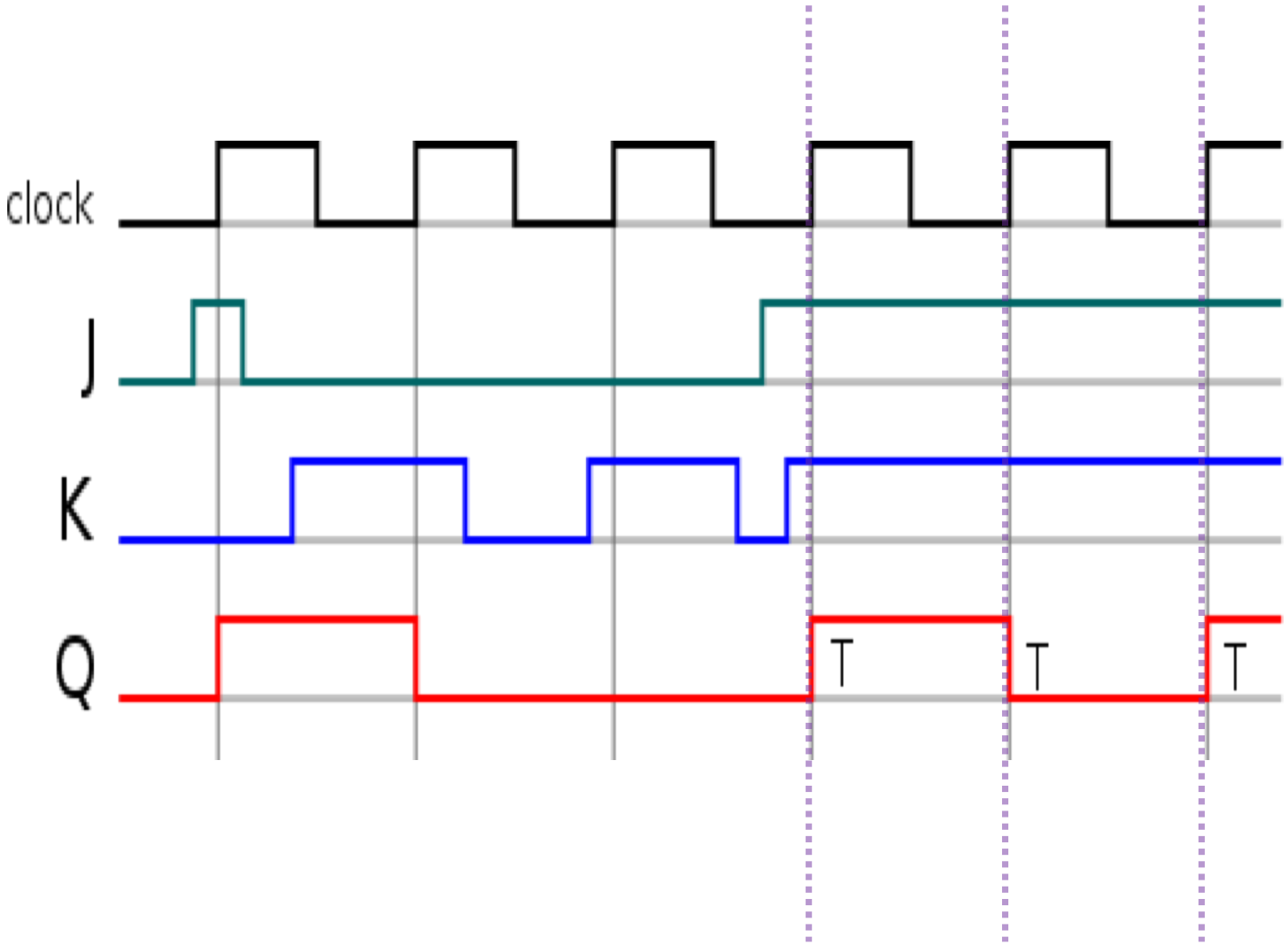
J	K	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	$\overline{Q}(t)$

JK Flip-Flop
(timing diagram)



J	K	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	$\overline{Q}$(t)

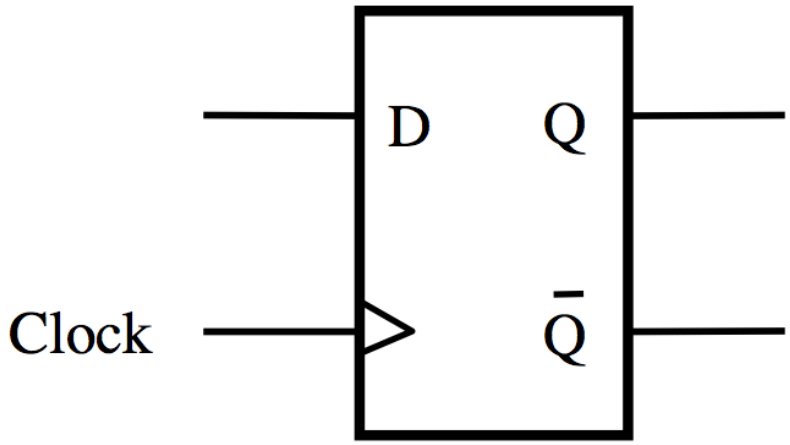
JK Flip-Flop
(timing diagram)



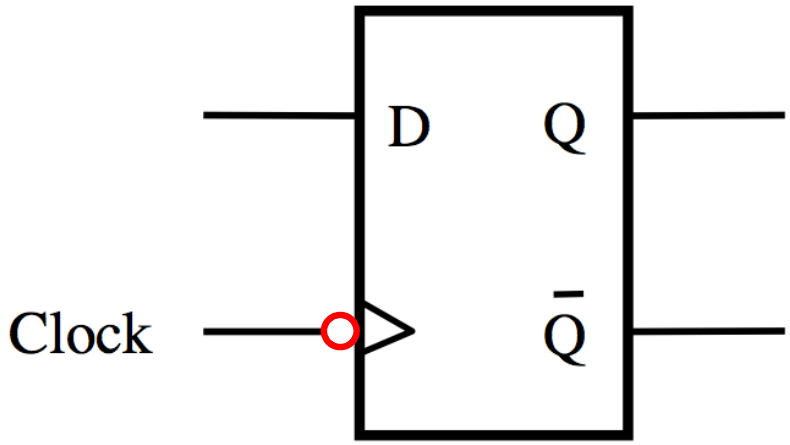
J	K	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	$\overline{Q}$(t)

Complete Wiring Diagrams

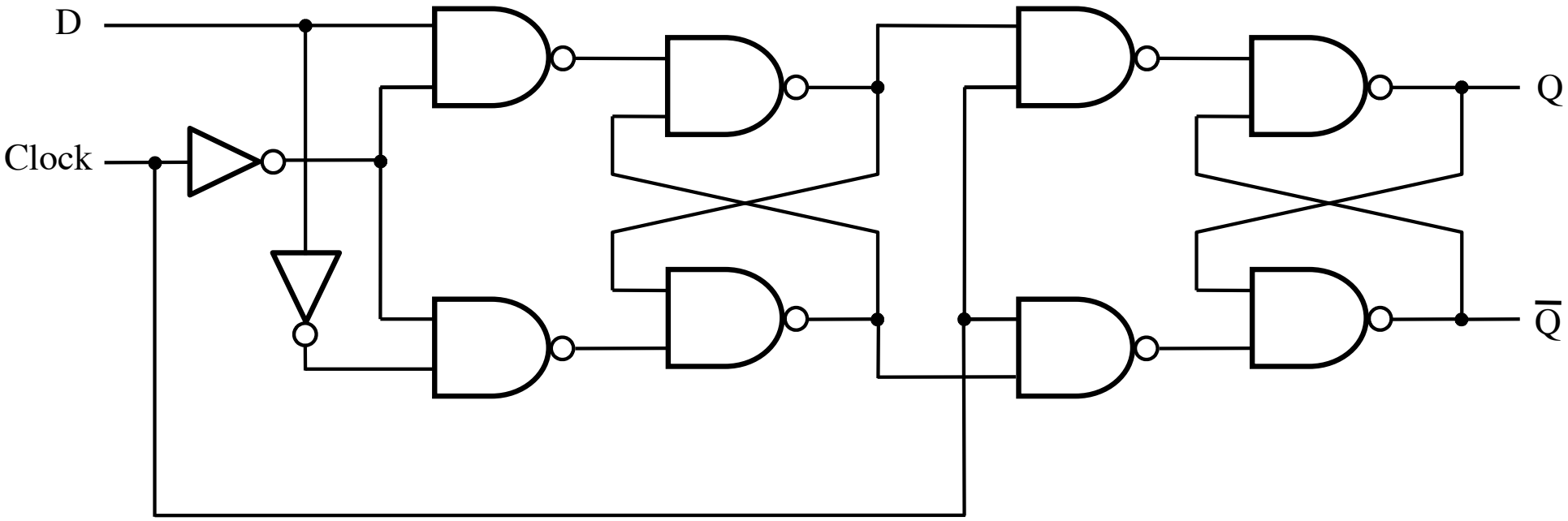
Positive-Edge-Triggered D Flip-Flop



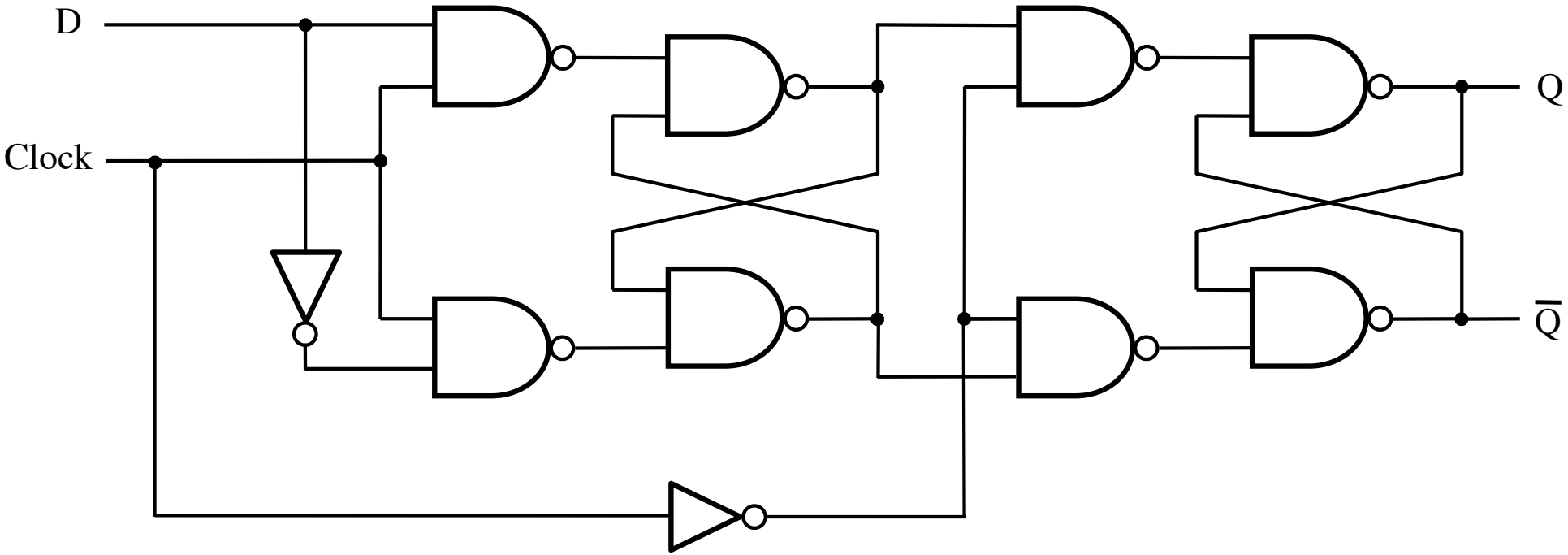
Negative-Edge-Triggered D Flip-Flop



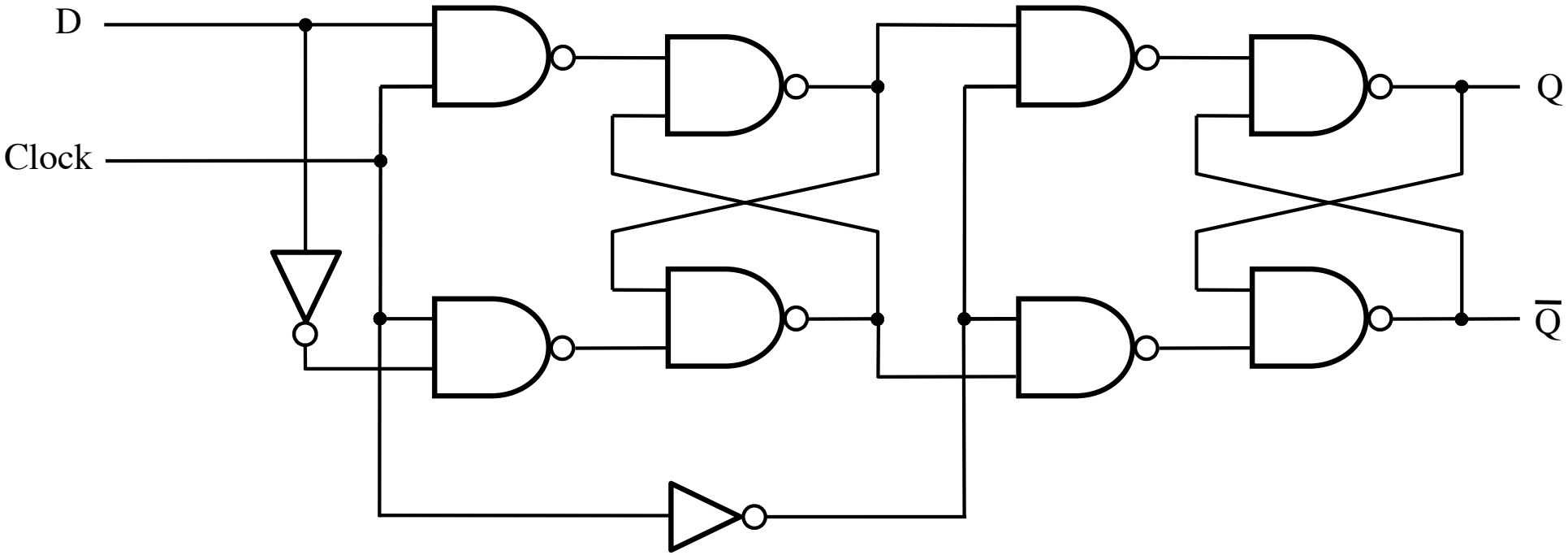
The Complete Wiring Diagram for a Positive-Edge-Triggered D Flip-Flop



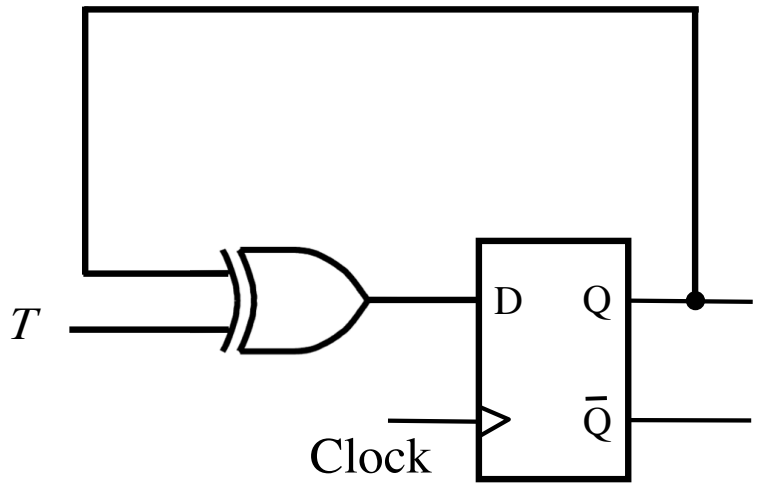
The Complete Wiring Diagram for a Negative-Edge-Triggered D Flip-Flop



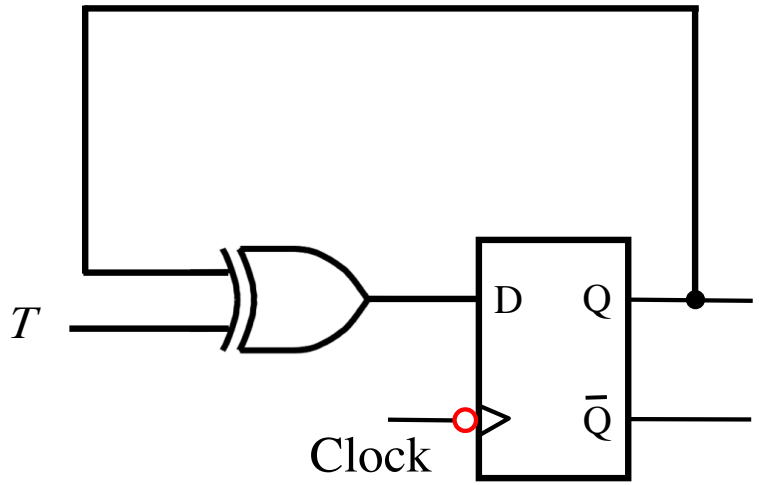
The Complete Wiring Diagram for a Negative-Edge-Triggered D Flip-Flop



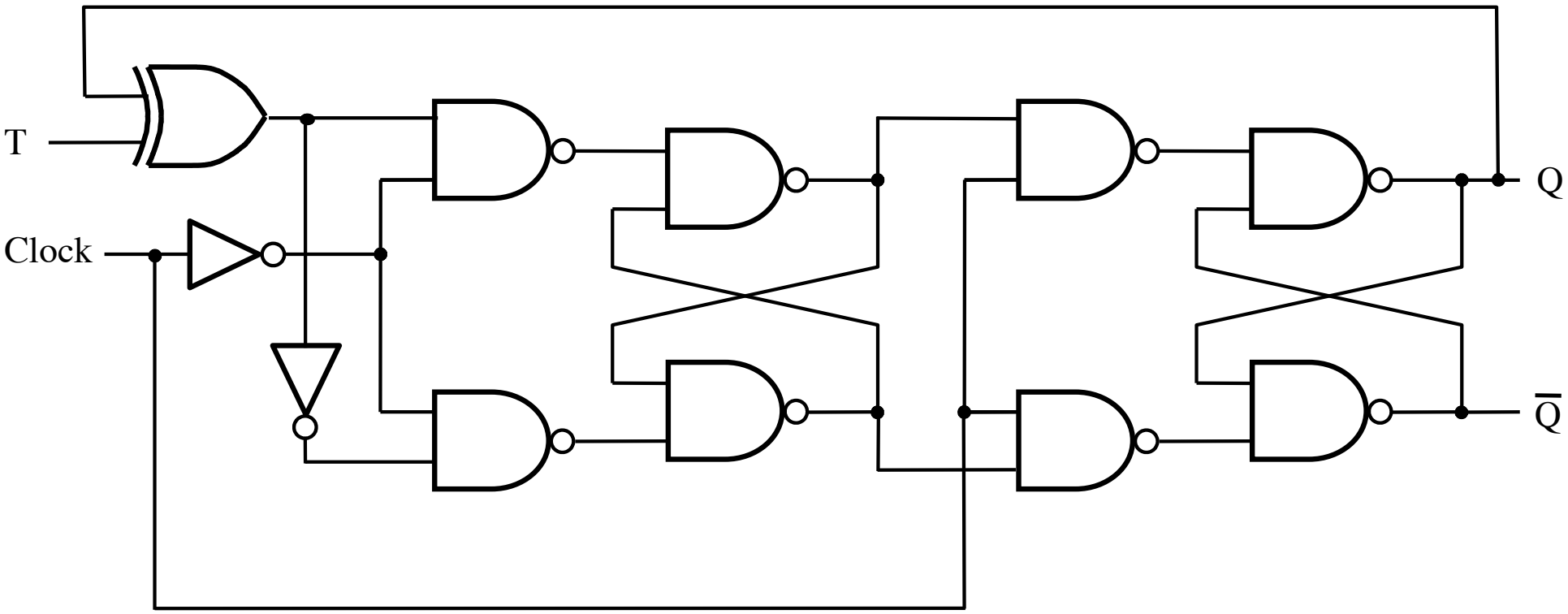
Positive-Edge-Triggered T Flip-Flop



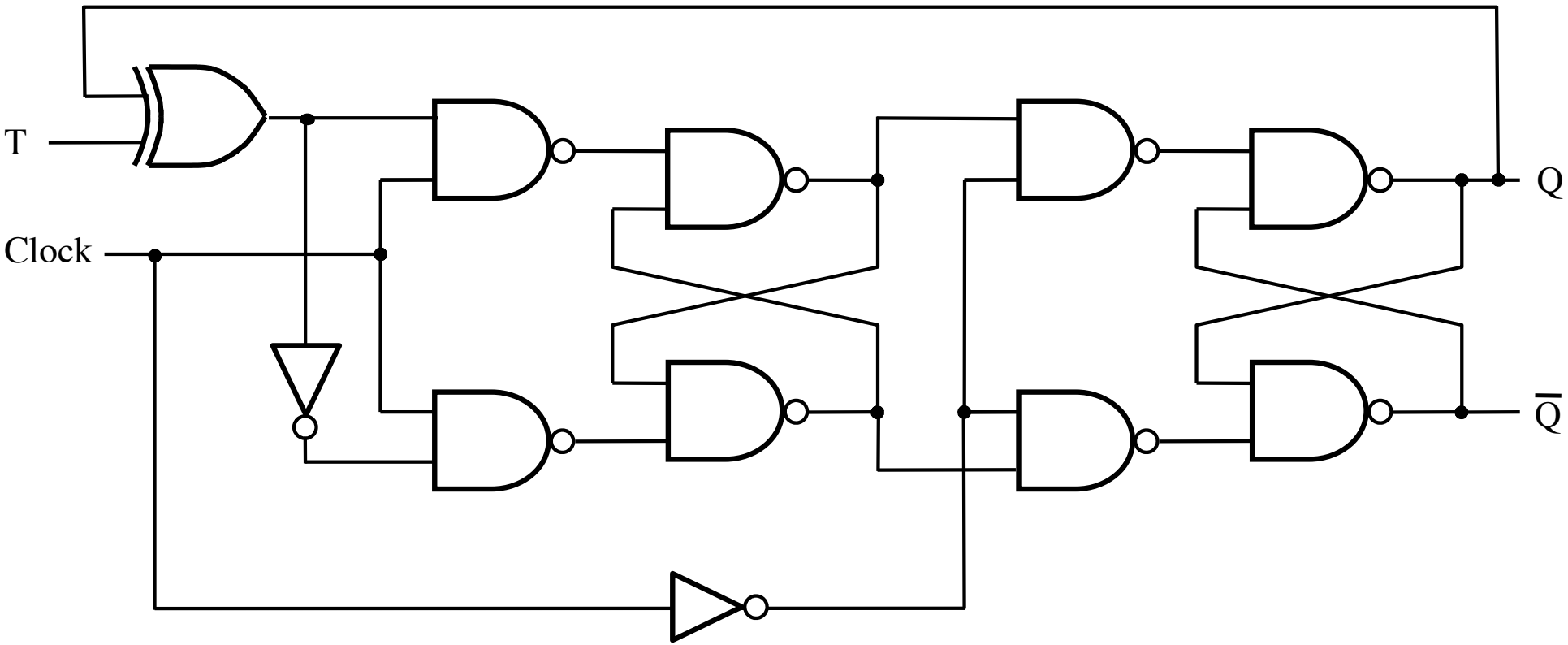
Negative-Edge-Triggered T Flip-Flop



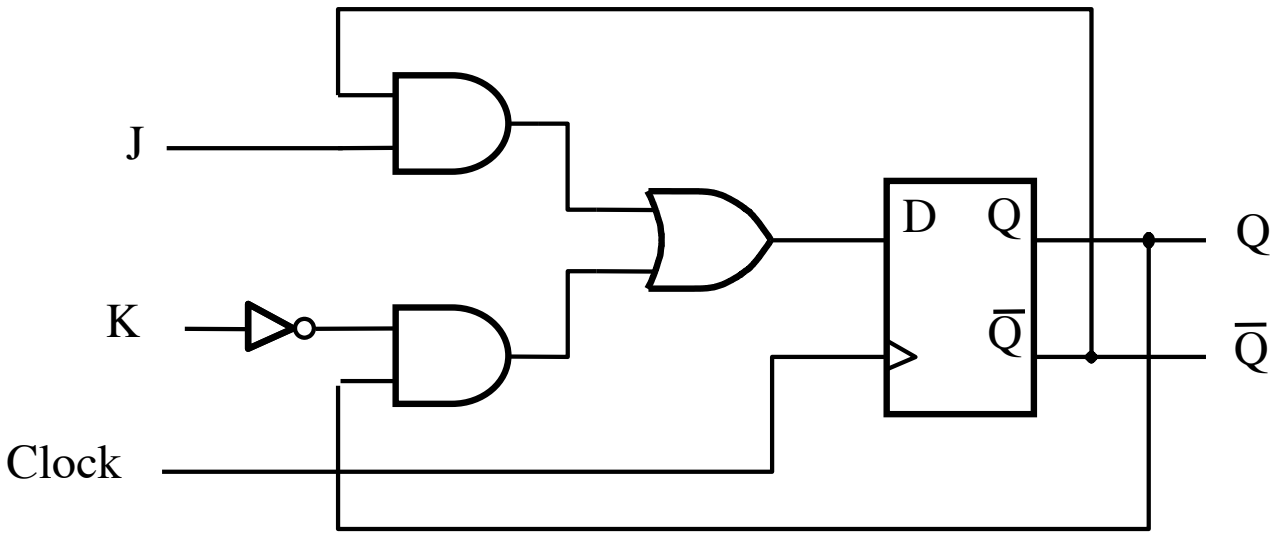
The Complete Wiring Diagram for a Positive-Edge-Triggered T Flip-Flop



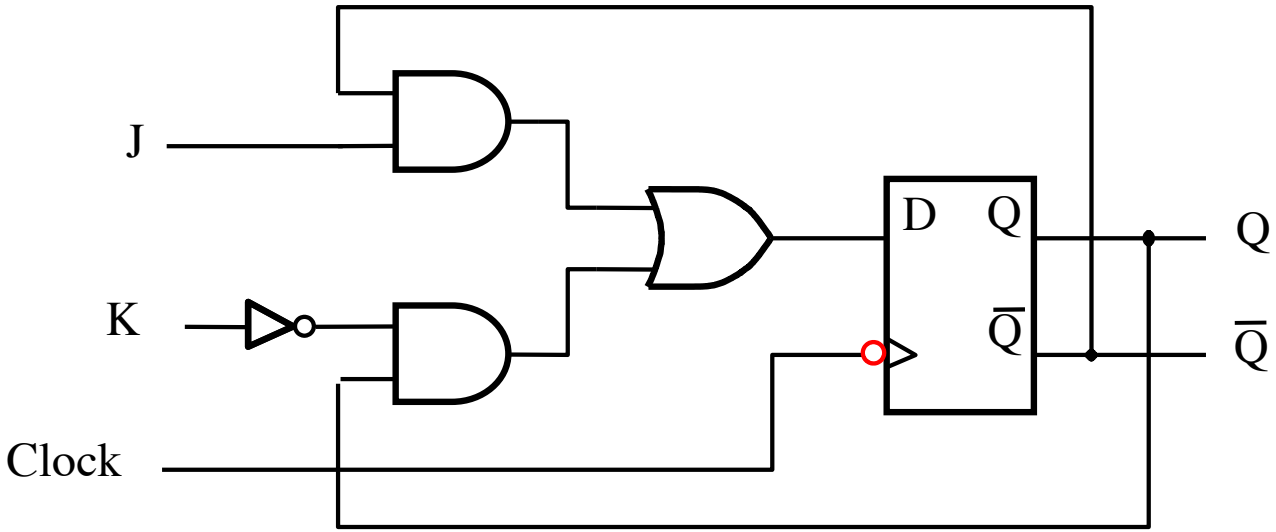
The Complete Wiring Diagram for a Negative-Edge-Triggered T Flip-Flop



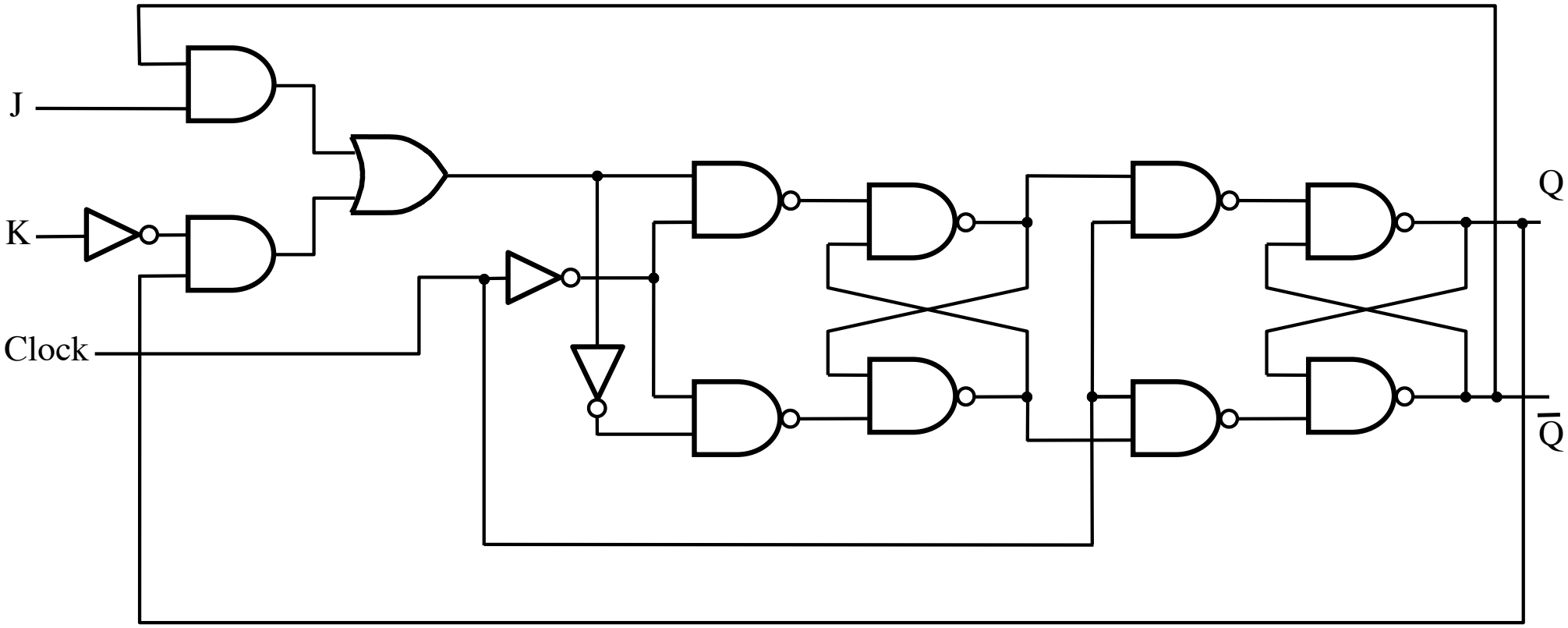
Positive-Edge-Triggered JK Flip-Flop



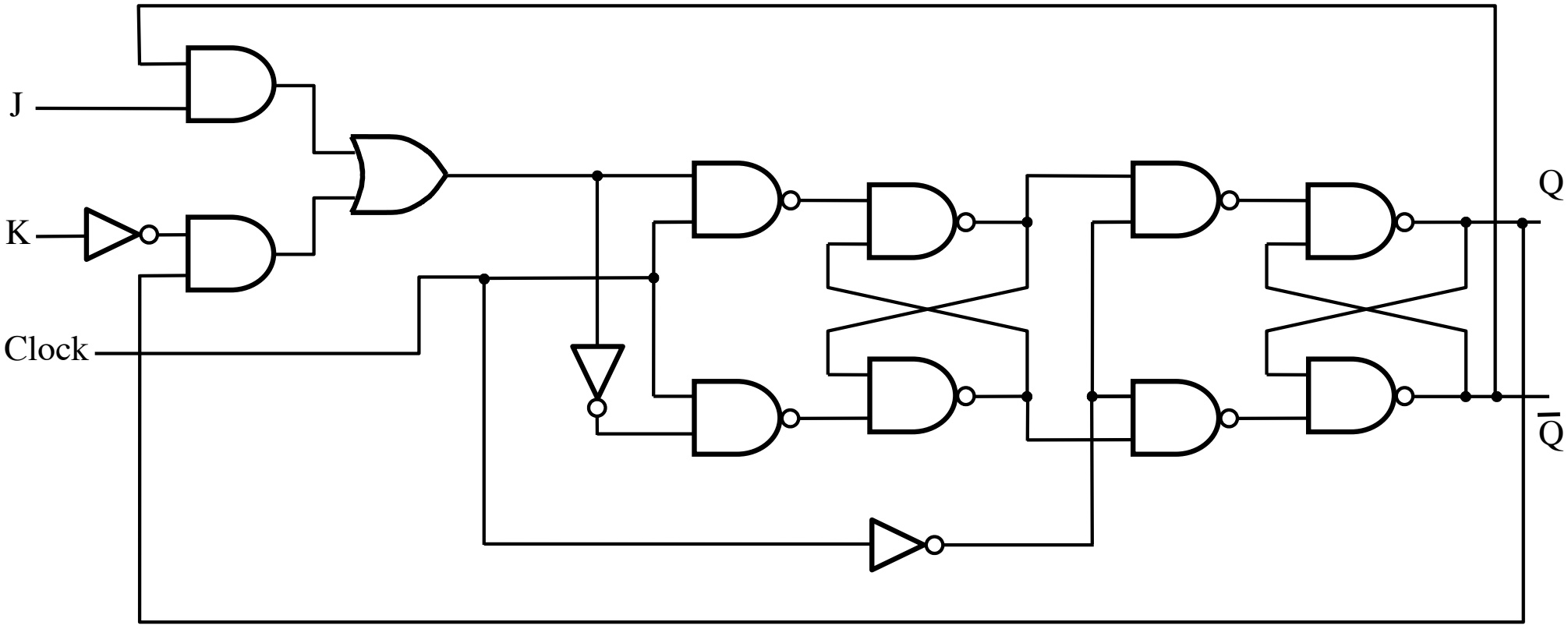
Negative-Edge-Triggered JK Flip-Flop



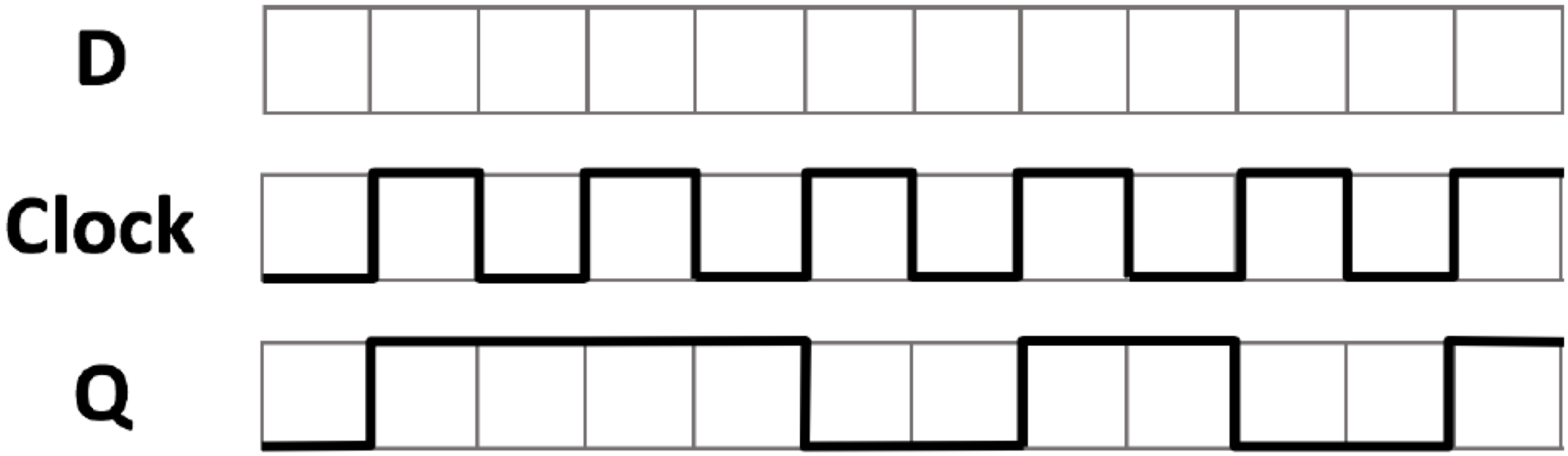
The Complete Wiring Diagram for a Positive-Edge-Triggered JK Flip-Flop

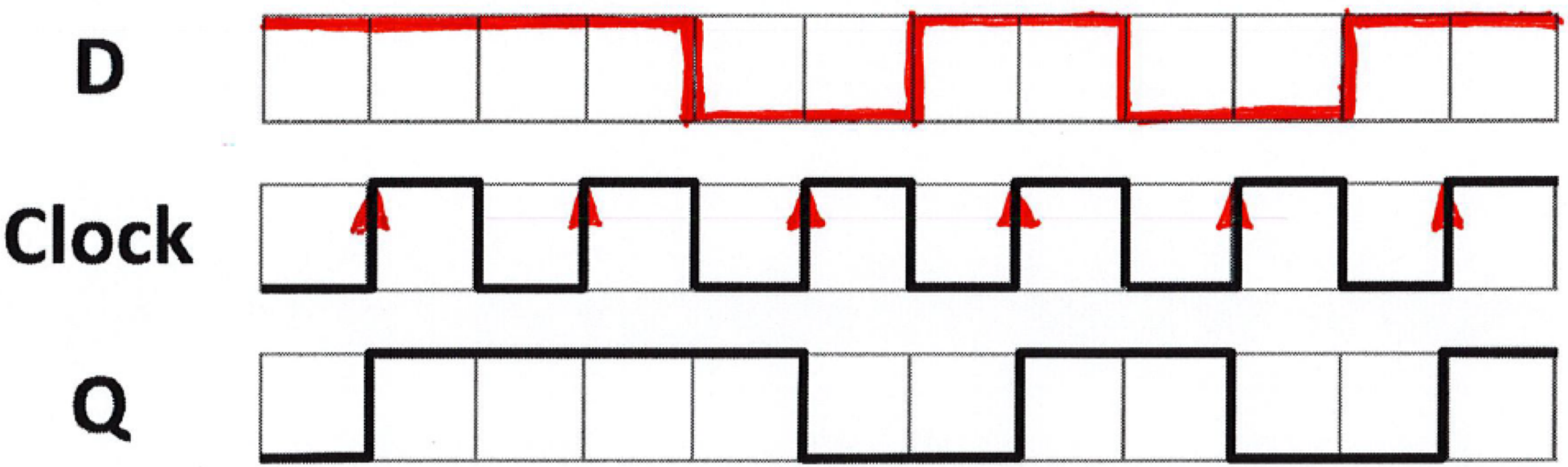


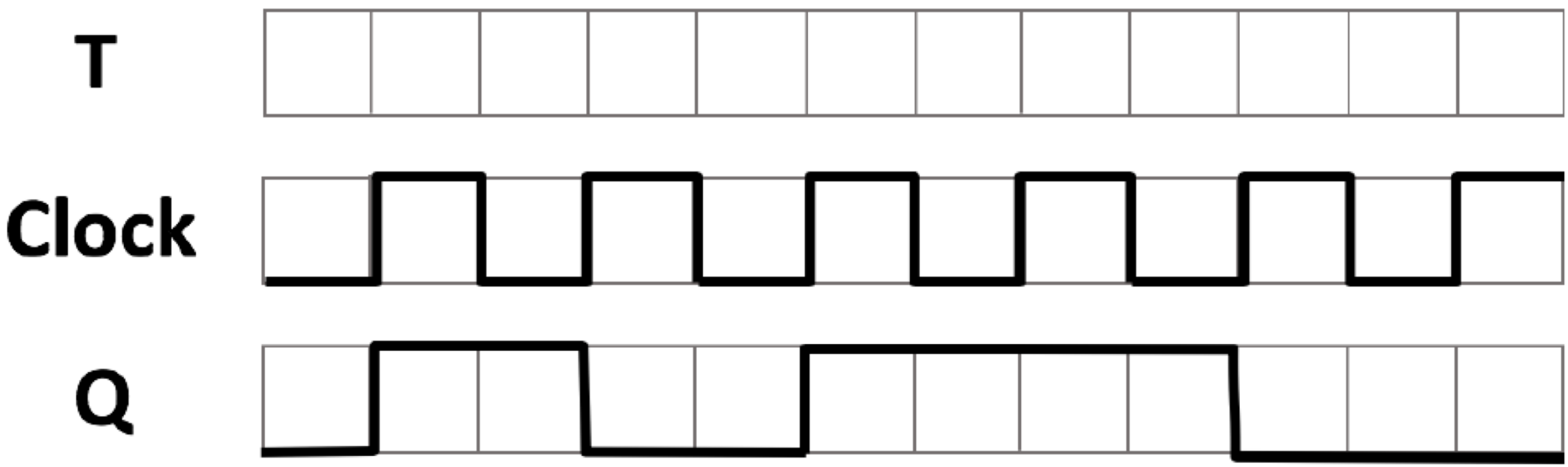
The Complete Wiring Diagram for a Negative-Edge-Triggered JK Flip-Flop

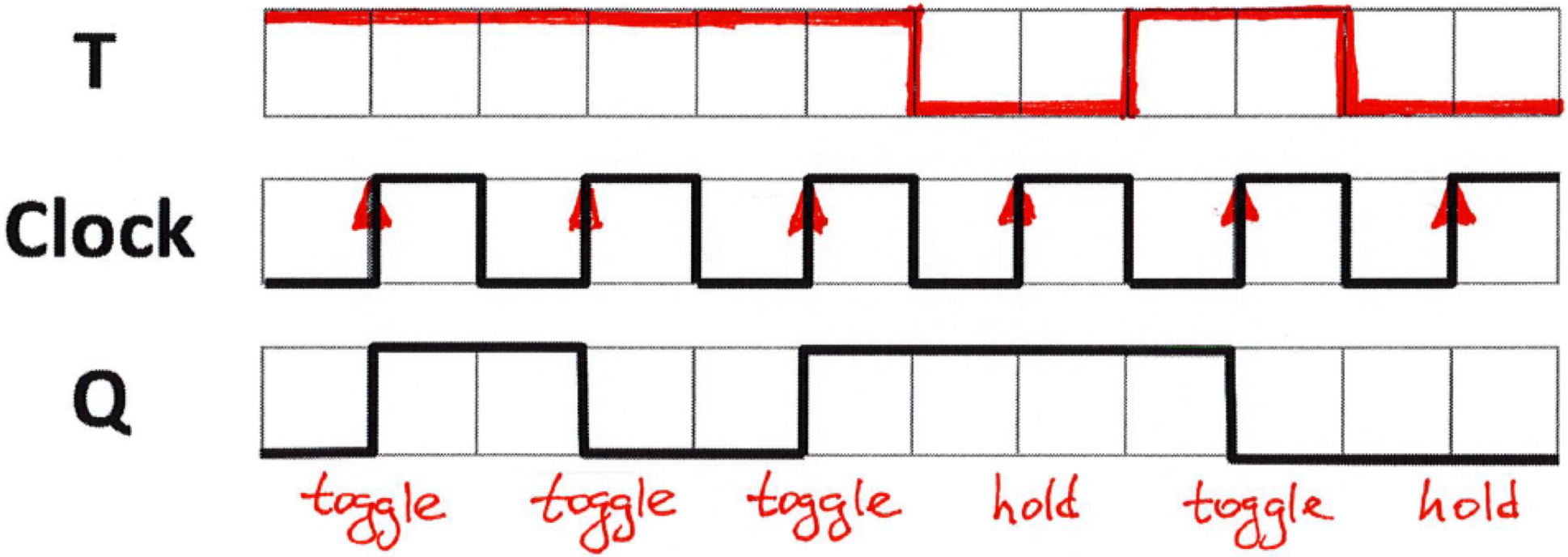


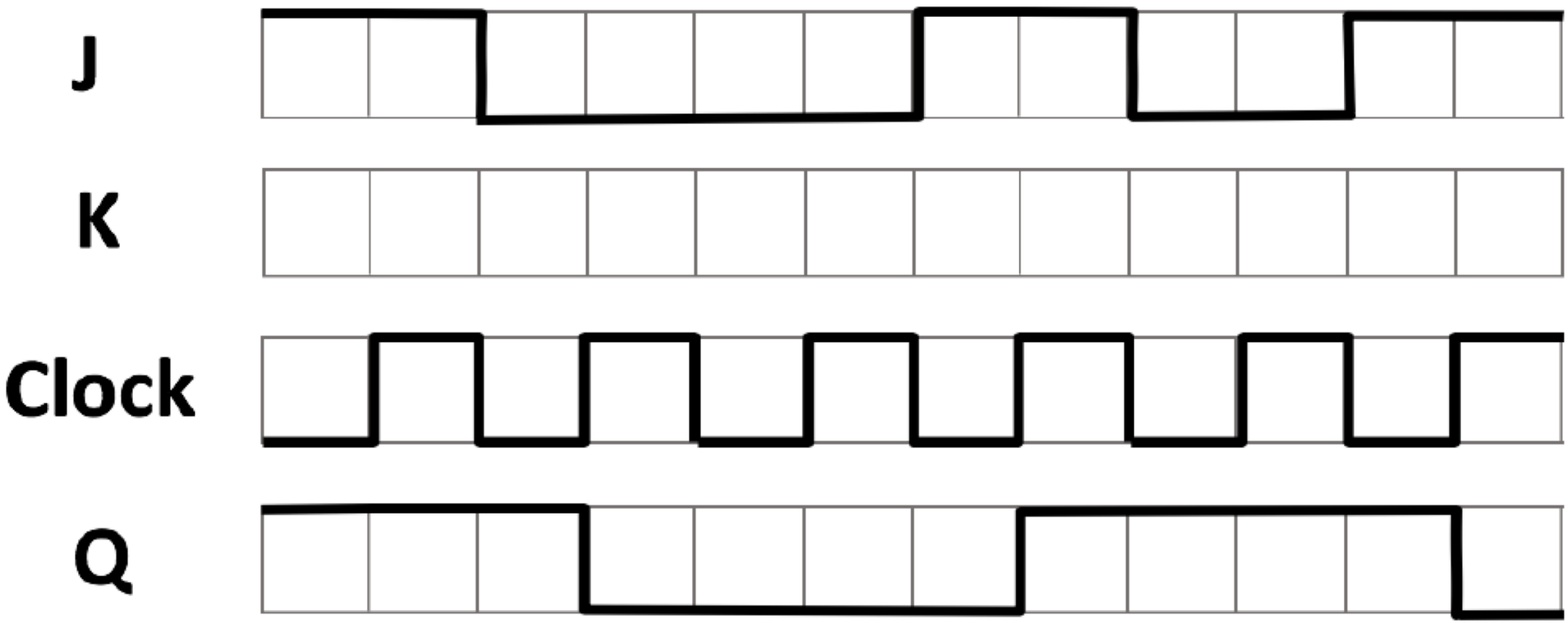
Complete the Timing diagrams (for positive-edge-triggered F-F)

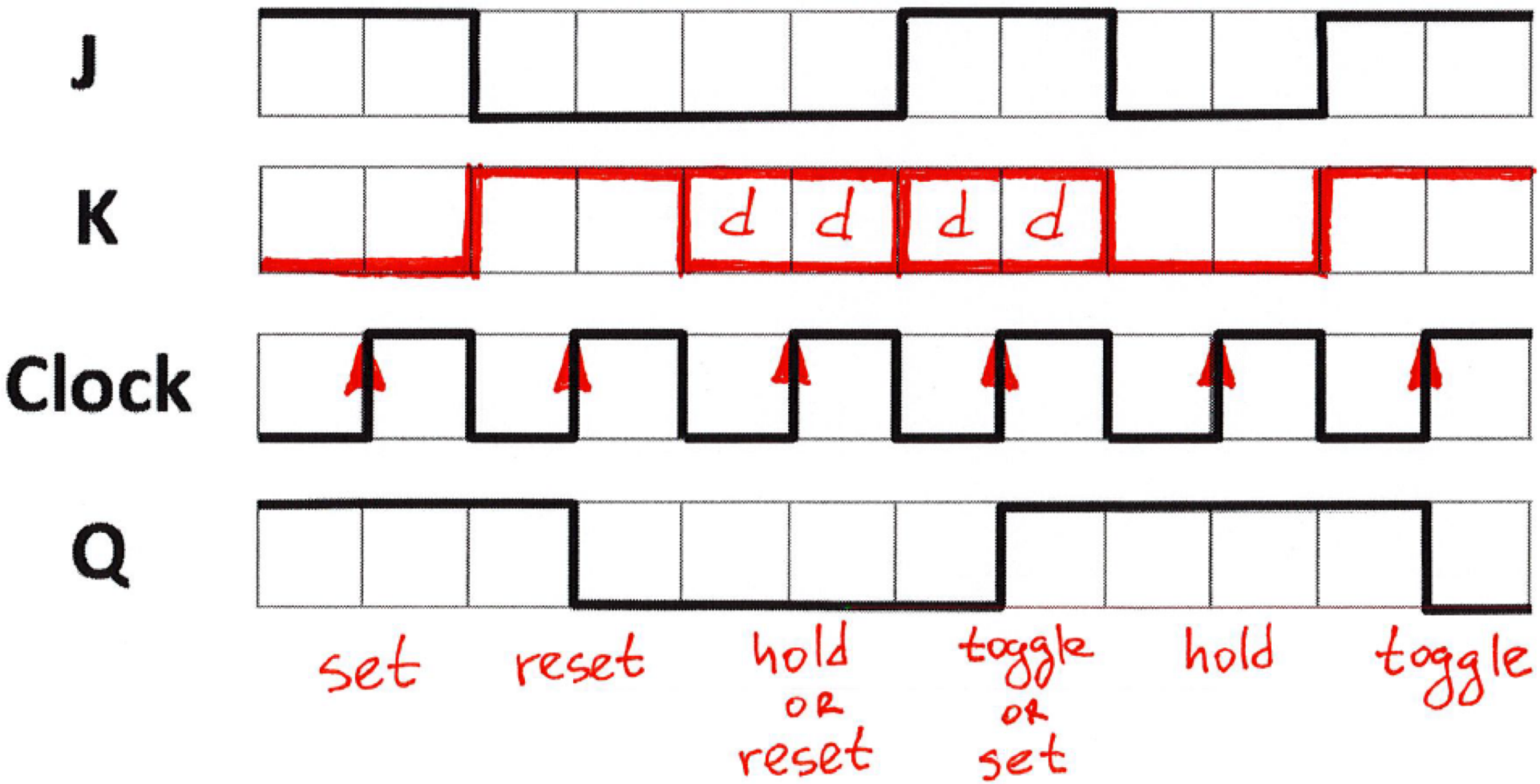

D
Clock
Q


D
Clock
Q

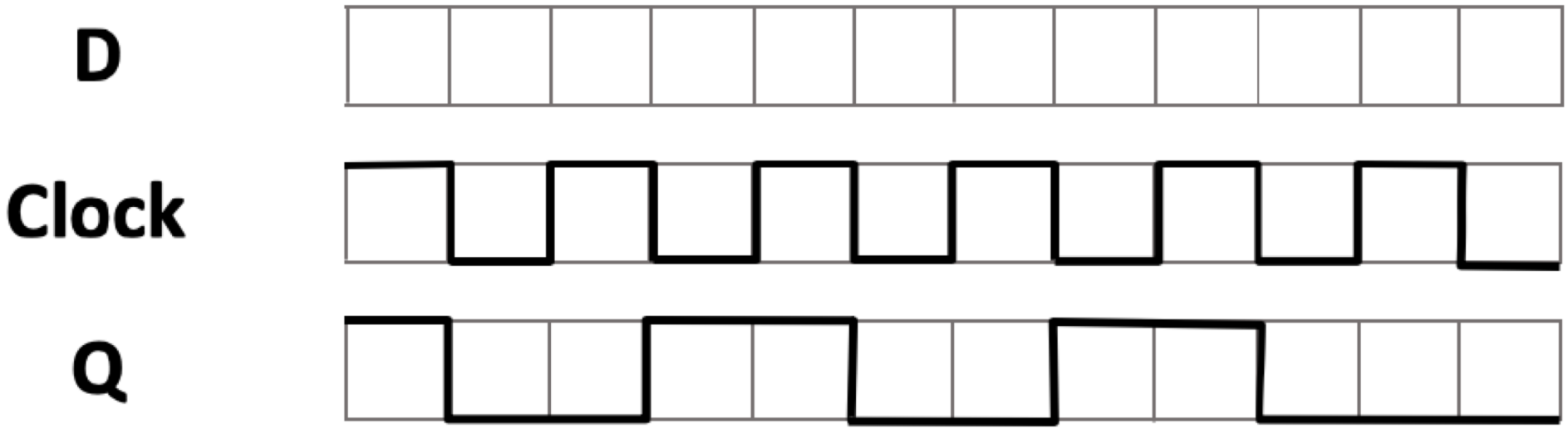

T
Clock
Q

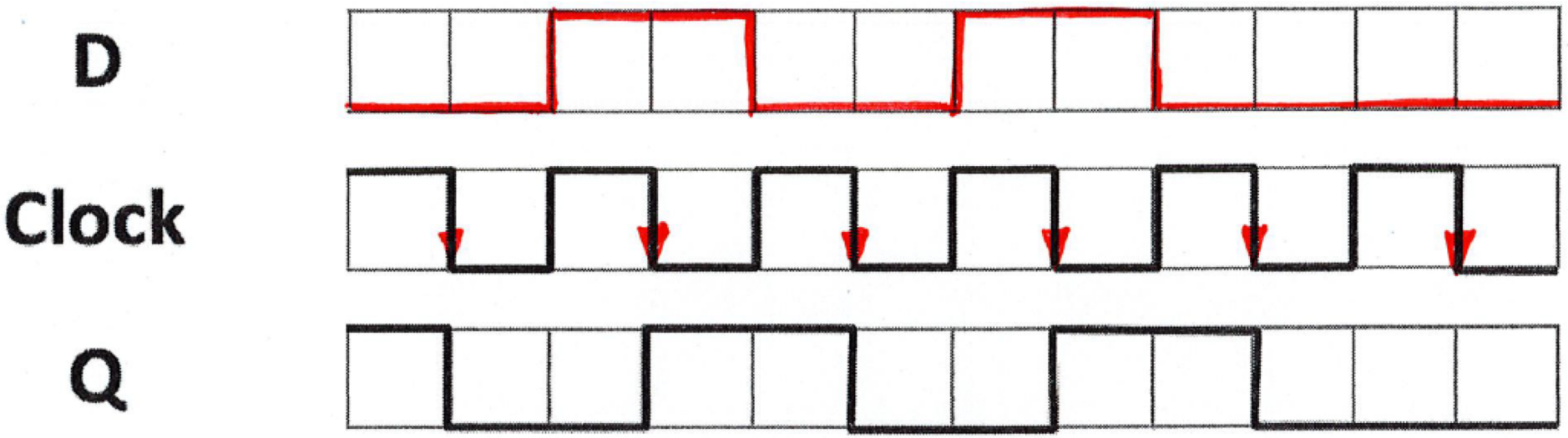

T
Clock
Q
toggle
toggle
toggle
hold
toggle
hold

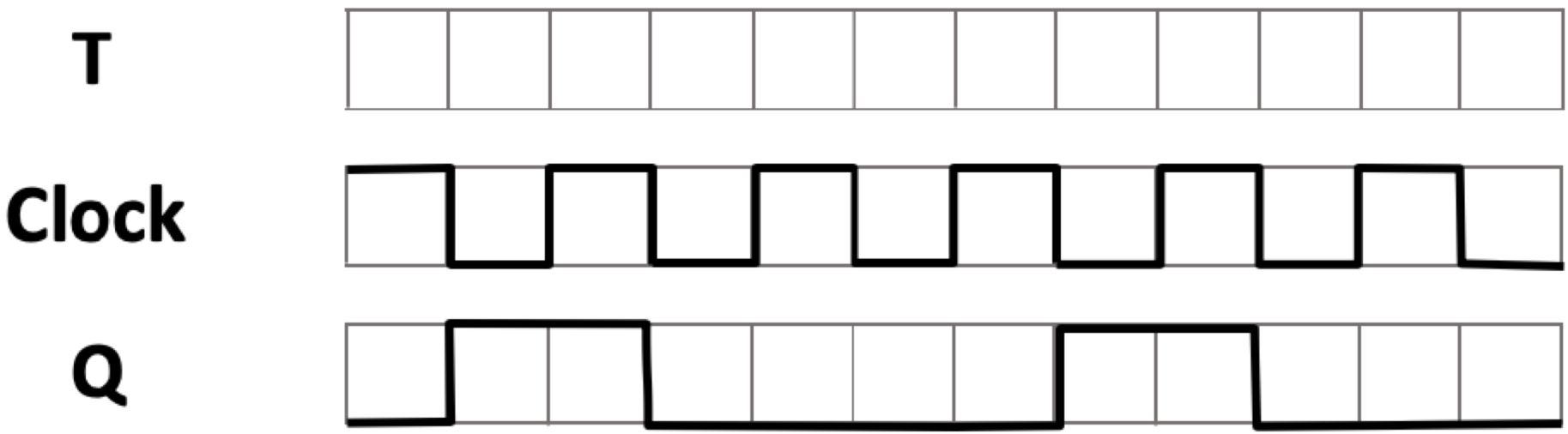

J
K
Clock
Q

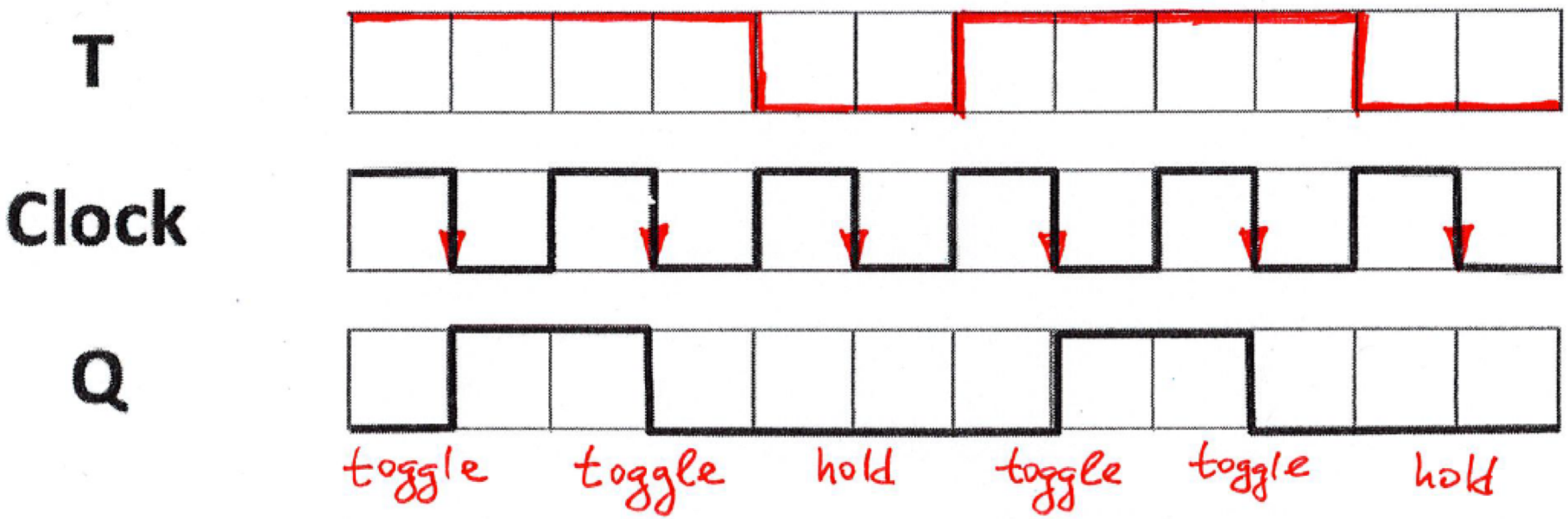

J
K
d d d d
Clock
Q
set
reset
hold
or
reset
toggle
or
set
hold
toggle

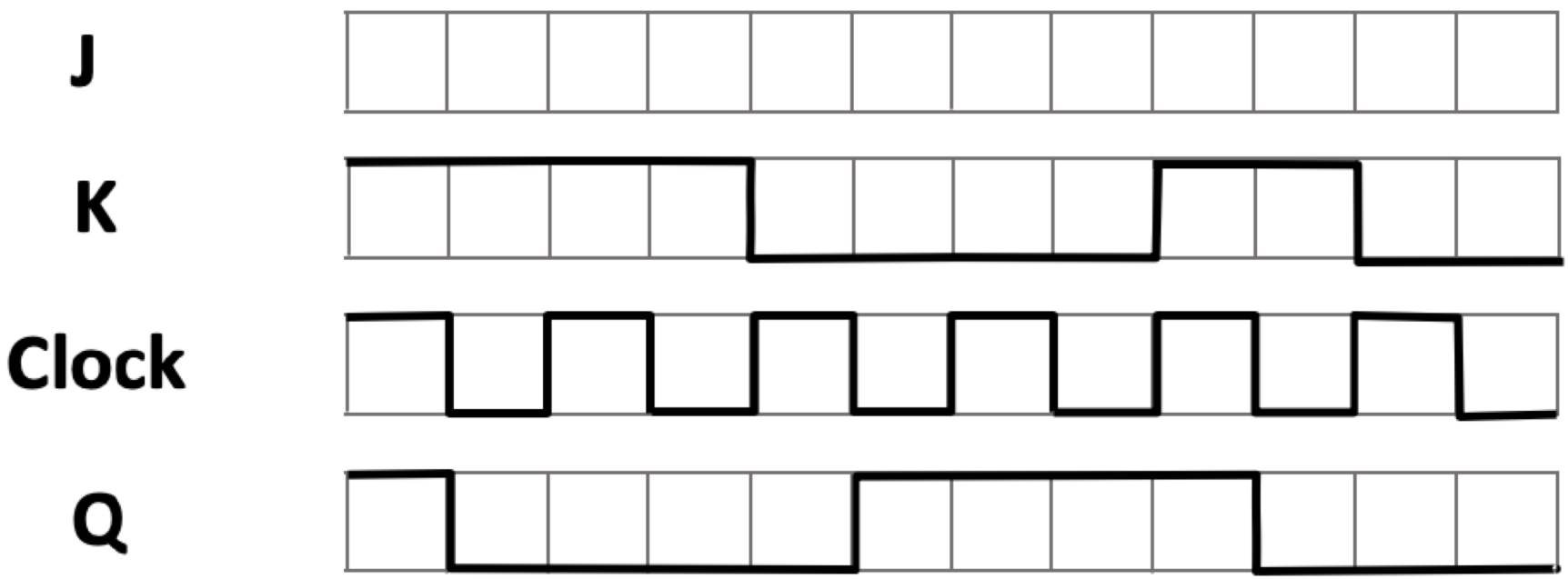
Complete the Timing diagrams (for negative-edge-triggered F-F)

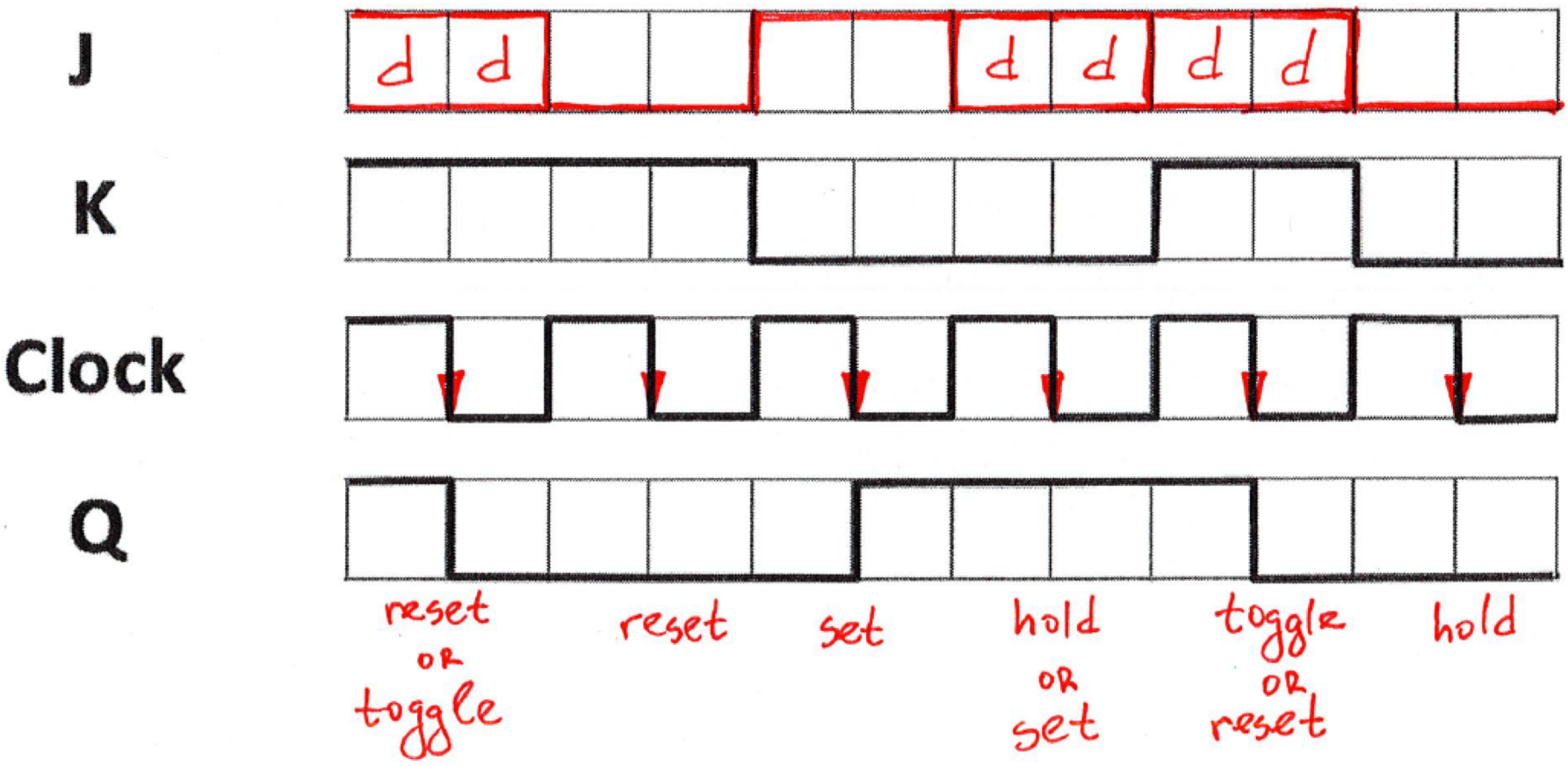

D
Clock
Q


D
Clock
Q


T
Clock
Q


T
Clock
Q
toggle
toggle
hold
toggle
toggle
hold


J
K
Clock
Q


J
K
Clock
Q
d
d
d
d
d
d
reset
OR
toggle
reset
set
hold
OR
set
toggle
OR
reset
hold

Questions?

THE END