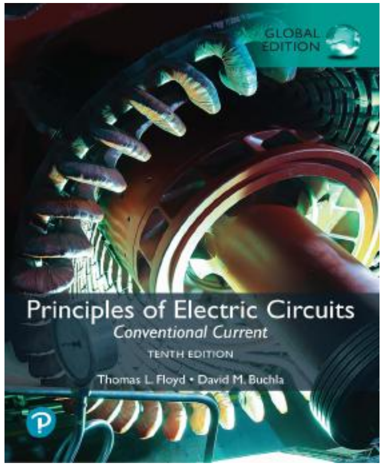
Principles of Electric Circuits: Conventional Current

Tenth Edition, Global Edition

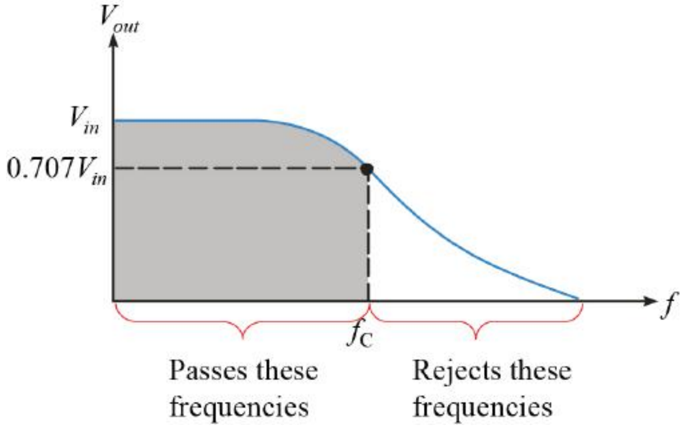


Chapter 18

Passive Filters

Summary: Low-pass filters (1 of 2)

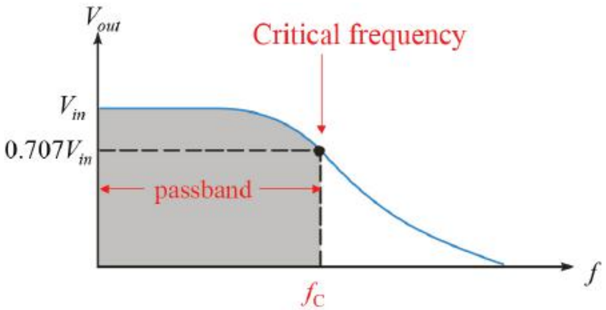
A low-pass filter allows signals with lower frequencies to pass while rejecting higher frequencies.



Summary: Low-pass filters (2 of 2)

The **passband** is defined as range of frequencies passed by a filter within a specified limit.

The **critical frequency** (also called the cutoff frequency, or –3dB frequency) is the frequency at which the output voltage is 70.7% of the maximum.



Summary: Decibels

Filter responses shown in plots and specifications are usually written in decibels, which is defined as

$$\text{dB} = 10\log\left(\frac{P_{out}}{P_{in}}\right)$$

Another useful definition for the decibel, when measuring voltages across the same impedance, is

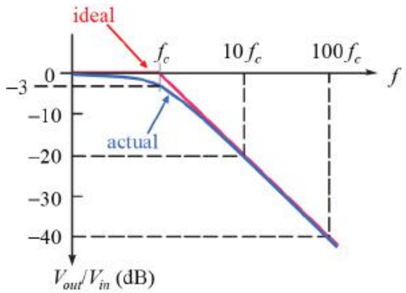
$$\text{dB} = 20\log\left(\frac{V_{out}}{V_{in}}\right)$$

Because it is a ratio, the decibel is dimensionless.

Summary: Bode plot (1 of 2)

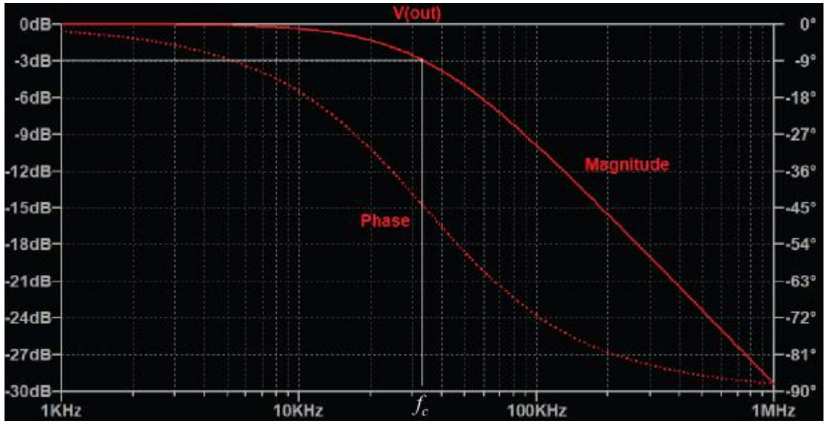
A Bode magnitude plot is a semilog response curve for a filter (log on *x* and decibels on *y*). For example, a basic low-pass filter ideally has the Bode plot shown. Actual filters roll-off to –3dB at f_c.

The roll-off rate of a basic *RC* or *RL* filter is –20 dB per decade.



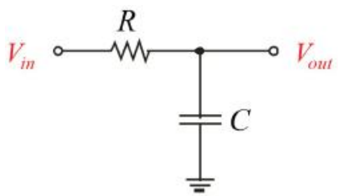
Summary: Bode plot (2 of 2)

The second type of Bode plot is a phase plot. This LTSpice plot shows both the magnitude and phase plot for the text Example 18-6.

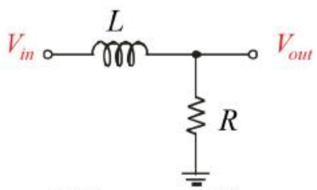


Summary: Low-pass filter circuits (1 of 3)

A basic low-pass filter can be constructed from either *RC* or *RL* components. The critical frequency for either type is found by setting *X* = *R*.



RC low-pass filter



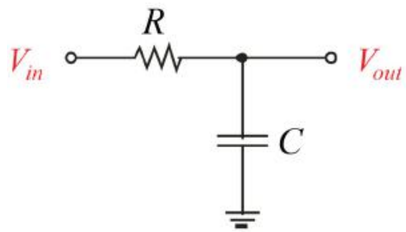
RL low-pass filter

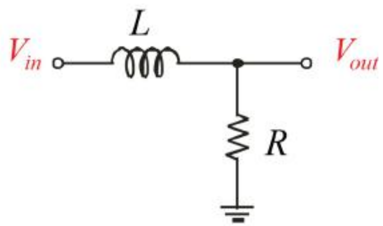
For the *RC* circuit, $f_c = \dfrac{1}{2\pi RC}$

For the *RL* circuit, $f_c = \dfrac{1}{2\pi\,(L/R)}$

Summary: Low-pass filter circuits (2 of 3)

The output voltage of a low-pass filter at any frequency can be derived from the voltage-divider equation.





For the *RC* circuit,

$$V_{out} = \left(\frac{X_C}{\sqrt{R^2 + X_C^{\,2}}}\right)V_{in}$$

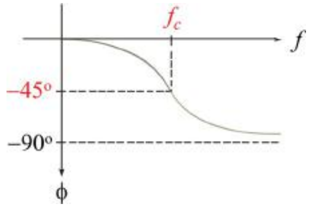
For the *RL* circuit,

$$V_{out} = \left(\frac{R}{\sqrt{R^2 + X_L^{\,2}}}\right)V_{in}$$

Summary: Low-pass filter circuits (3 of 3)

The basic *RC* and *RL* low-pass circuits are both lag networks. At the critical frequency the phase shift is –45° for both circuits.

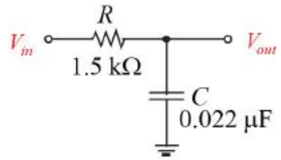
Phase response for both circuits:



Summary: LTSpice

Example

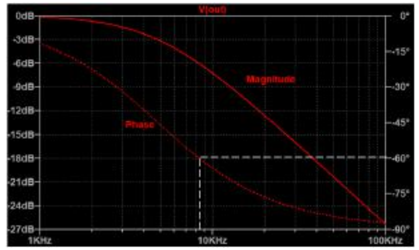
Determine f_c for the circuit.



$$f_C = \frac{1}{2\pi RC} = \frac{1}{2\pi\,(1.5\text{k}\Omega)(0.022\ \mu\text{F})}$$

$$= 4.82\ \text{kHz}$$

You can view the Bode plot using either LTSpice or Multisim. Here is the LTSpice file for the circuit.

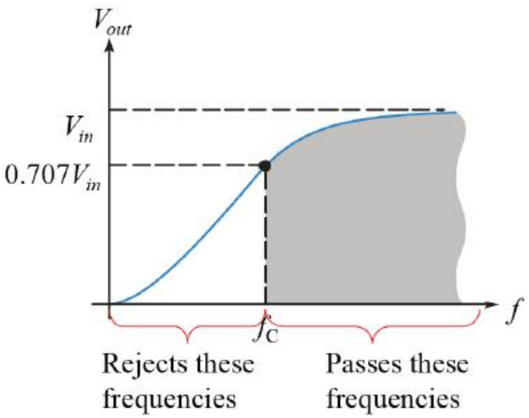


Question:

At what frequency is the phase shift −60o? 8.4 kHz

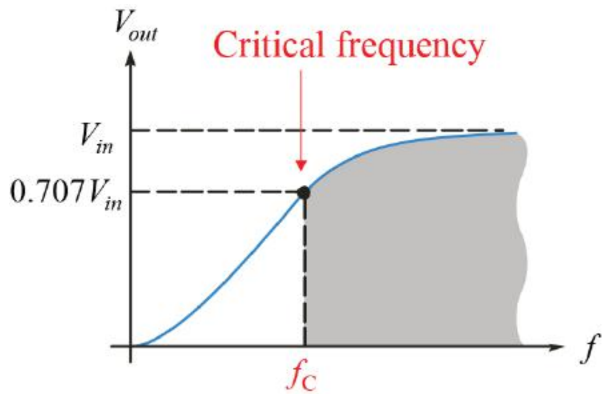
Summary: High-pass filters (1 of 6)

A high-pass filter allows signals with higher frequencies to pass while rejecting lower frequencies.



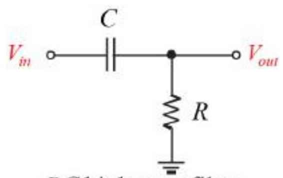
Summary: High-pass filters (2 of 6)

The **critical frequency** is the same as in the low-pass case, namely the frequency at which the output voltage is 70.7% of the maximum.

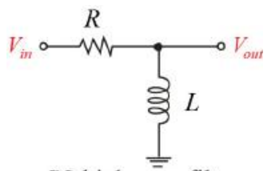


Summary: High-pass filters (3 of 6)

As with low-pass filters, a basic high-pass filter can be constructed from either *RC* or *RL* components. The critical frequency for either type is found by setting *X* = *R* and is the same as the low-pass f_c.



RC high-pass filter



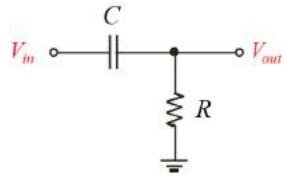
RL high-pass filter

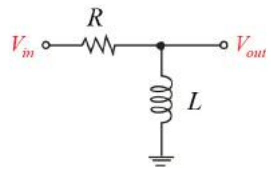
For the *RC* circuit, $f_c = \dfrac{1}{2\pi RC}$

For the *RL* circuit, $f_c = \dfrac{1}{2\pi (L/R)}$

Summary: High-pass filters (4 of 6)

The output voltage of a high-pass filter at any frequency can also be derived from the voltage-divider equation.





For the *RC* circuit,

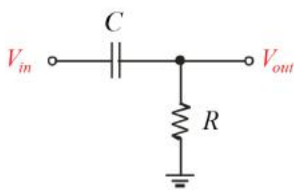
$$V_{out} = \left(\frac{R}{\sqrt{R^2 + X_C^{\,2}}}\right)V_{in}$$

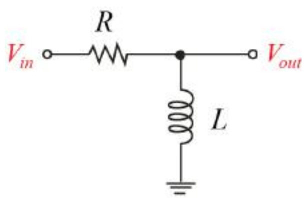
For the *RL* circuit,

$$V_{out} = \left(\frac{X_L}{\sqrt{R^2 + X_L^{\,2}}}\right)V_{in}$$

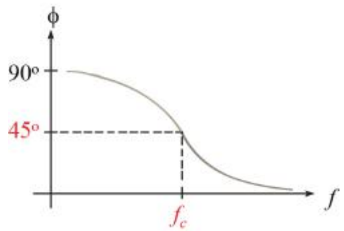
Summary: High-pass filters (5 of 6)

The basic *RC* and *RL* high-pass circuits are both lead networks. At the critical frequency, the phase shift is +45° for both circuits.





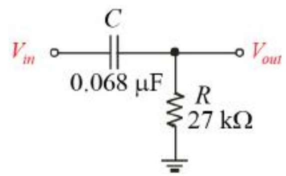
Phase response for both circuits:



Summary: High-pass filters (6 of 6)

Example

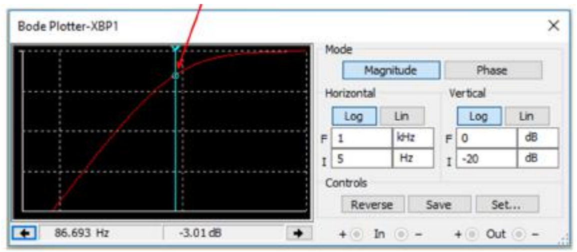
Determine f_c for the circuit.



$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi (27\text{ k}\Omega)(0.068\ \mu\text{F})}$$

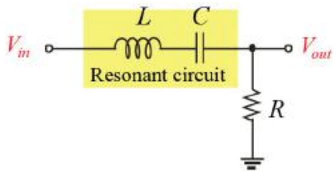
$$= 86.7\text{ Hz}$$

You can view the Bode plot using either LTSpice or Multisim. Here is the Multisim result. The cursor is at f_c, confirming the calculation.

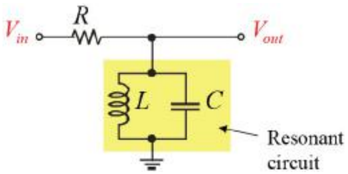


Summary: Band-pass filter circuits (1 of 2)

Basic band-pass filter circuits can be constructed from a combination of low-pass and high-pass filters or using resonant circuits.



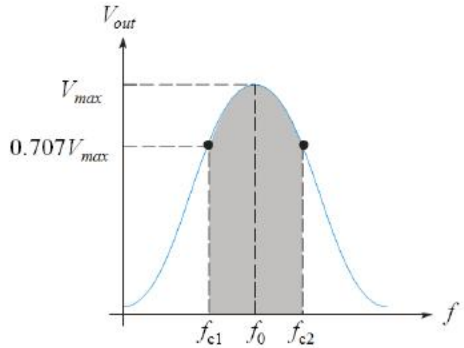
Series resonant band-pass filter



Parallel resonant band-pass filter

Summary: Band-pass filter circuits (2 of 2)

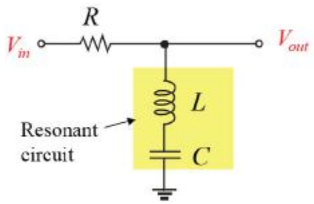
A generalized response for a band-pass filter is shown.



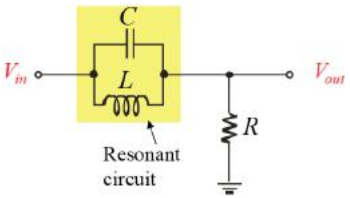
The bandwidth is measured between the frequencies where the output drops to $0.707V_{max}$.

Summary: Band-stop filter circuits (1 of 4)

Basic band-stop filter circuits can also be constructed from a combination of low-pass and high-pass filters or using resonant circuits. Resonant band-stop filters are shown.



Series resonant band-stop filter

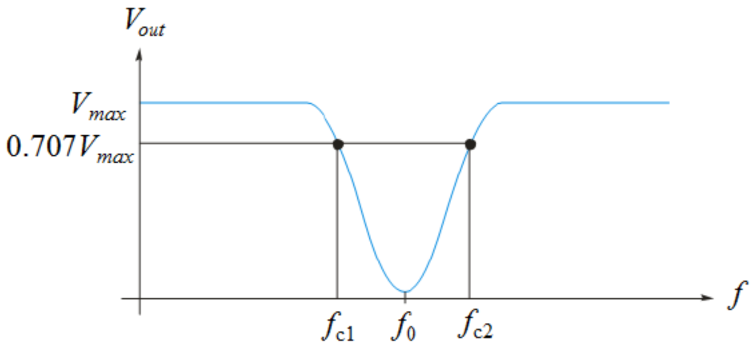


Parallel resonant band-stop filter

Summary: Band-stop filter circuits (2 of 4)

A generalized response for a band-stop filter is shown.

The bandwidth is measured between the frequencies where the output drops to $0.707V_{max}$.

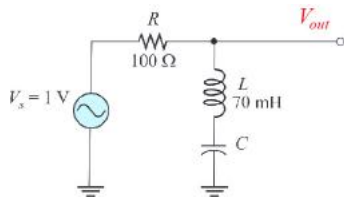


Summary: Band-stop filter circuits (3 of 4)

A series resonant notch filter is shown. R_W for the inductor is 10 Ω. What value of C is required to reject 60 Hz?

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

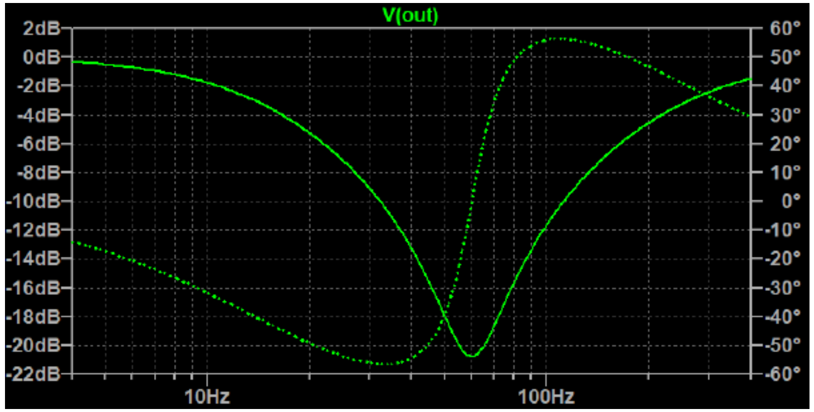
$$C = \left(\frac{1}{2\pi\sqrt{L}\,f_0}\right)^2 = \left(\frac{1}{2\pi\sqrt{70\text{ mH}}\,(60\text{ Hz})}\right)^2 = 101$$



The following slide shows the Bode plot from an LTSpice calculation.

Summary: Band-stop filter circuits (4 of 4)

LTSpice simulation:



Summary: Key ideas (1 of 2)

- Basic low-pass and high-pass filters are formed from *RC* or *RL* circuits.
- With low-pass filters, the output lags the input.
- With high-pass filters, the output leads the input.
- The roll off rate of basic low-pass or high-pass filters is –20dB/decade.
- A band-pass filter passes frequencies between two critical frequencies and rejects all others.

Summary: Key ideas (2 of 2)

- A band-stop filter rejects frequencies between two critical frequencies and passes all others.
- Band-pass and band-stop filters can be made from both series and parallel resonant circuits.
- The bandwidth of a resonant filter is determined by the *Q* and the resonant frequency.
- The output voltage at a critical frequency is 70.7% of the maximum.

Key ideas (1 of 3)

Low-pass filter A type of filter that passes all frequencies below a critical frequency and rejects all frequencies above that critical frequency.

Passband The range of frequencies passed by a filter.

Critical frequency (f_c) The frequency at which a filter's output voltage is 70.7% of the maximum.

Roll-off The rate of decrease of a filter's frequency response.

Key ideas (2 of 3)

Attenuation A reduction of the output signal compared to the input signal, resulting in a ratio with a value less than 1 for the output voltage to the input voltage for a circuit.

Decade A tenfold change in the frequency or other parameter.

Bode plot A graph of a filter's frequency response showing the change in the output voltage to the input voltage ratio expressed in dB as a function of frequency for a constant input voltage.

Key ideas (3 of 3)

High-pass filter A type of filter that passes all frequencies above a critical frequency and rejects all frequencies below that critical frequency.

Band-pass filter A filter that passes a range of frequencies lying between two critical frequencies and rejects the frequencies lying above and below that range.

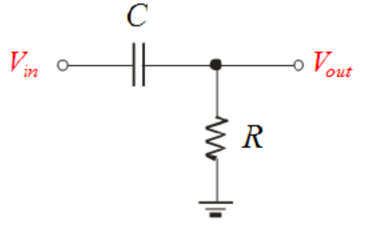
Center frequency The resonant frequency of a band-pass or band-stop filter.

Band-stop filter A filter that rejects a range of frequencies lying between two critical frequencies and passes frequencies above and below that range.

Quiz (1 of 11)

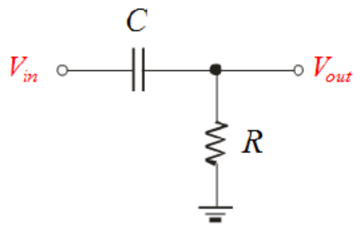
1. The basic filter circuit shown is a

   a. low-pass
   b. high-pass
   c. band-pass
   d. band-stop



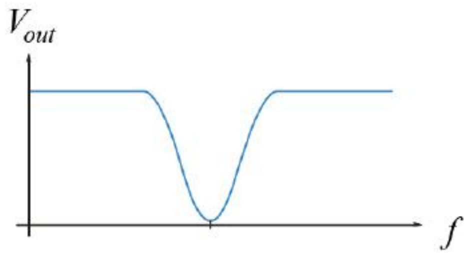
Quiz (2 of 11)

2. For the circuit shown, the output voltage will
   a. lead the input voltage
   b. lag the input voltage
   c. be in phase with the input voltage
   d. be out of phase with the input voltage



Quiz (3 of 11)

3. A filter with the response shown is a
   a. low-pass filter
   b. high-pass filter
   c. band-pass filter
   d. band-stop filter



Pearson Copyright © 2022, 2010, 2007 Pearson Education, Ltd. All Rights Reserved

Quiz (4 of 11)

4. A series resonant filter can be made into a
   a. low-pass filter
   b. high-pass filter
   c. band-pass filter
   d. none of the above

Pearson Copyright © 2022, 2010, 2007 Pearson Education, Ltd. All Rights Reserved

Quiz (5 of 11)

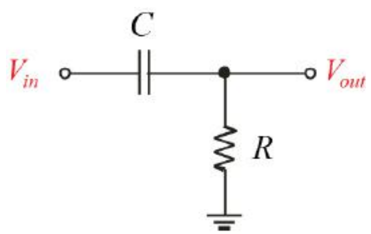
5. For the circuit shown, the output voltage at any frequency can be expressed as

a. $V_{out} = \left(\frac{R}{\sqrt{R^2 + X_C^2}}\right)V_{in}$

b. $V_{out} = 0.707V_{max}$

c. $V_{out} = \left(\frac{X_C}{\sqrt{R^2 + X_C^2}}\right)V_{in}$

d. $V_{out} = 0.707V_{in}$



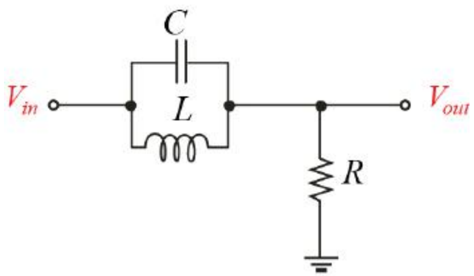
Pearson Copyright © 2022, 2010, 2007 Pearson Education, Ltd. All Rights Reserved

Quiz (6 of 11)

6. At the critical frequency, the phase shift of a low-pass filter is
   a. 0°
   b. −45°
   c. +45°
   d. none of the above

Quiz (7 of 11)

7. The basic filter circuit shown is a
   a. low-pass
   b. high-pass
   c. band-pass
   d. band-stop



Quiz (8 of 11)

8. At the cutoff frequency, the output of a filter is
   a. equal to the input
   b. −3 dB
   c. −6 dB
   d. −20 dB

Quiz (9 of 11)

9. The definition of a decibel is
   a. $\text{dB} = 10\log\left(\frac{P_{out}}{P_{in}}\right)$
   b. $\text{dB} = 20\log\left(\frac{V_{out}}{V_{in}}\right)$
   c. both a and b are correct
   d. none of the above

Quiz (10 of 11)

10. The measurement unit used with decibels is the
    a. watt
    b. volt
    c. ohm
    d. none of the above

Quiz (11 of 11)

Answers:

1. b
2. a
3. d
4. c
5. a
6. b
7. d
8. b
9. c
10. d