

Math Workbook

Grade 11 CST

Term 2

Graph Theory Unit – Definitions

3.1 GRAPH THEORY DEFINITIONS

In graph theory, a graph is a collection of dots and lines. The lines show relationships that exist between the elements of a set (the dots).

Ex: An airline has flights to 5 different airports (Ottawa, Halifax, Toronto, Calgary, and Edmonton). The following is information about flights offered:

- From Ottawa, there are flights to Halifax and Toronto
- From Halifax, there are flights to Ottawa and Edmonton
- From Toronto, there are flights to Ottawa, Calgary, and Edmonton
- From Calgary, there are flights to Toronto and Edmonton
- From Edmonton, there are flights to Toronto, Halifax and Calgary

Draw a graph to represent this scenario.

Try this question!

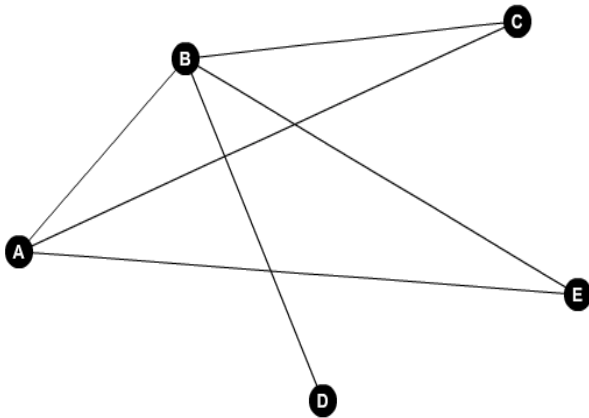
1) A company is installing a new computer network and some computers have to be directly connected to others.

- There are 6 computers (A, B, C, D, E, F)
- A must be directly connected to B, C, E, F
- B must be directly connected to A, C and D
- C must be directly connected to A, B
- D must be directly connected to B and E
- E must be directly connected to A and D
- F must be directly connected to A

Draw a graph to represent this scenario.

Graph Theory Unit – Definitions

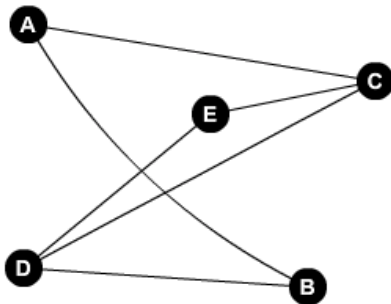
Definitions



- _____ – a dot on the graph. The vertices are the elements of the set (people, places, etc.). They are typically labelled with letters.
- _____ – a line on the graph. The edges represent relationships between the vertices. Edges are labelled using the letters of the two vertices they connect. It does not matter which vertex is listed first.
- _____ - the number of vertices in a graph.
- _____ – the number of edges that touch the vertex.

Try this question!

2) In the graph below, identify all the vertices and determine the degree of each vertex, identify all edges, and determine the order of the graph.

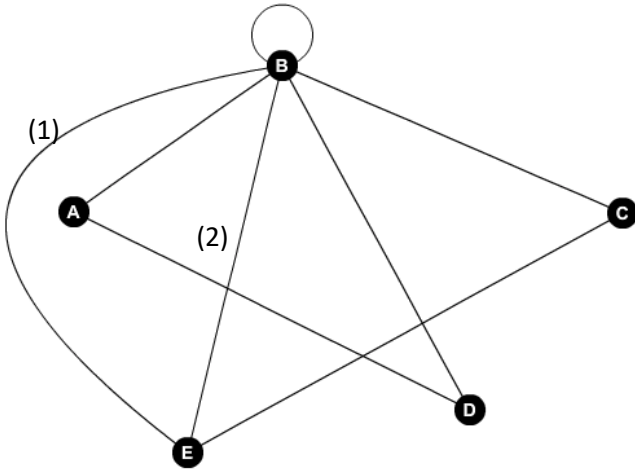


Vertices (and degree of each):

Edges:

Order:

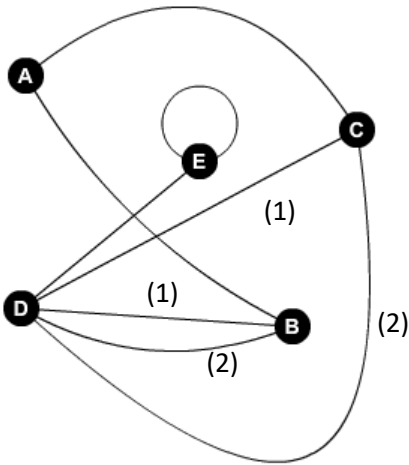
Graph Theory Unit – Definitions



- _____ – an edge that starts and ends at the same vertex.
- _____ – when two or more edges connect the same two vertices.

Try this question!

3) In the graph below, identify any loops and parallel edges

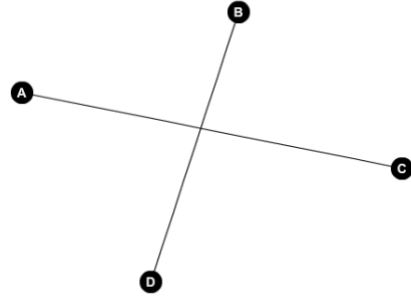
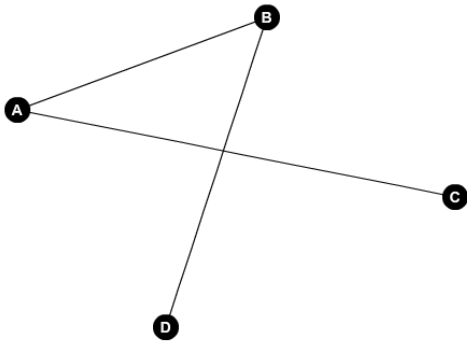


Loop(s):

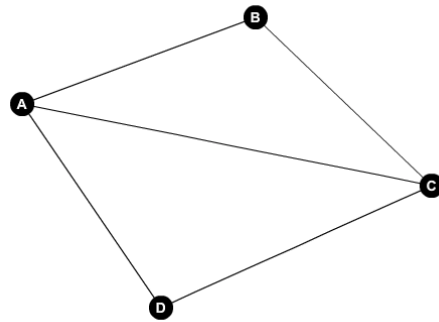
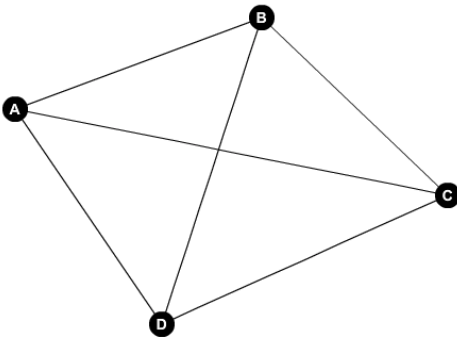
Parallel Edge(s):

Graph Theory Unit – Definitions

- A graph is connected when each vertex is connected to every other vertex by an edge *or by a series of edges*. This means that you can start at one vertex and get to every other vertex.



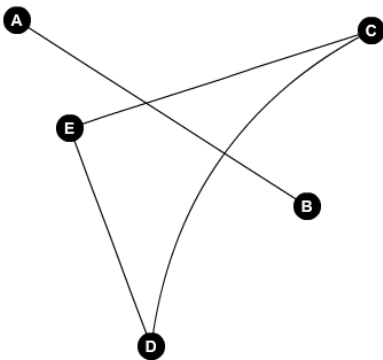
- A graph is complete – an edge connects every pair of vertices. This means there is only one edge separating every pair of vertices.



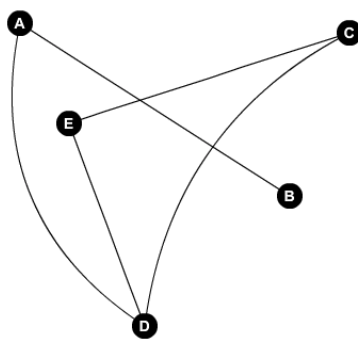
Try this question!

4) Determine if the graphs below are connected, complete, or neither.

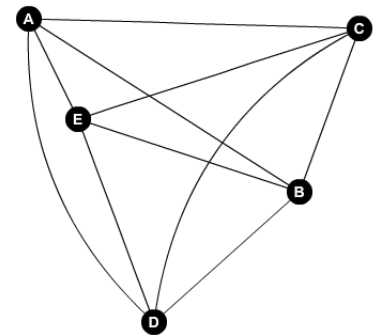
a)



b)

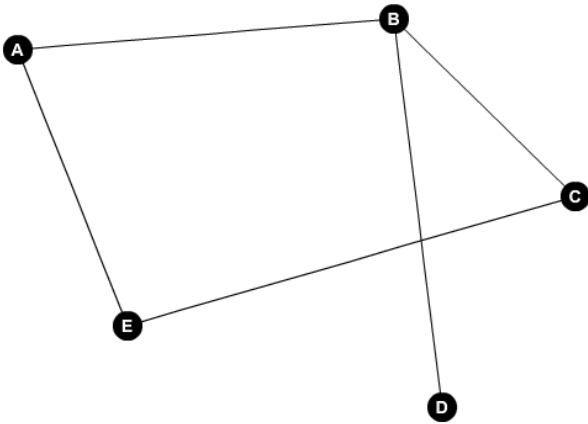


c)



Graph Theory Unit – Definitions

- The _____ of a graph is a graph that contains the edges necessary to complete the initial graph. You can think about this as the “missing edges”.

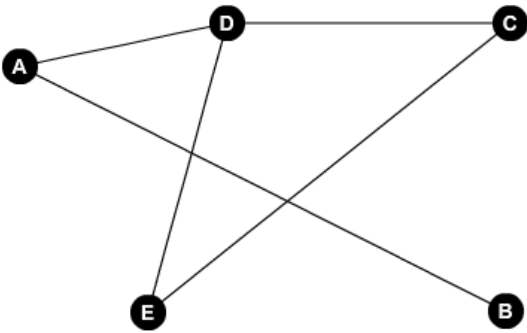


A graph

The Complement

Try this question!

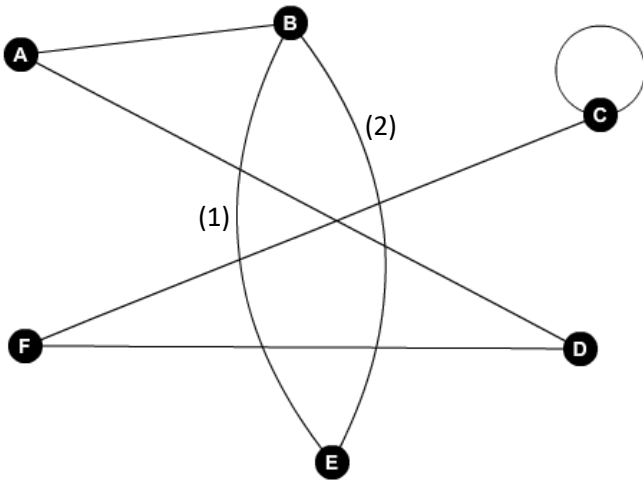
5) Create the complement of the graph given below.



Graph Theory Unit – Definitions

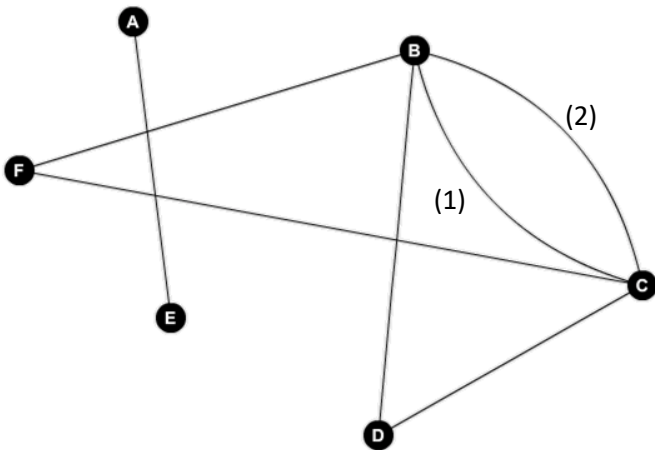
Practice Questions

6)



- a) List all vertices and the degree of each
- b) List all edges
- c) Determine the order of the graph
- d) Identify any loops
- e) Identify any parallel edges
- f) Determine whether the graph is connected
- g) Determine whether the graph is complete
- h) Draw the complement of the graph

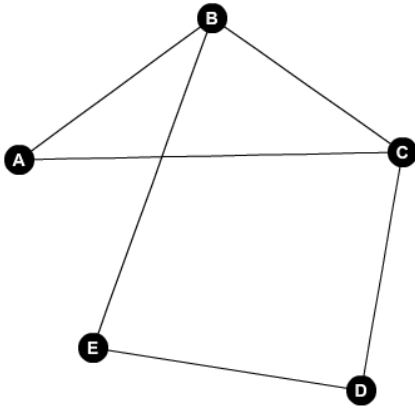
7)



- a) List all vertices and the degree of each
- b) List all edges
- c) Determine the order of the graph
- d) Identify any loops
- e) Identify any parallel edges
- f) Determine whether the graph is connected
- g) Determine whether the graph is complete
- h) Draw the complement of the graph

Graph Theory Unit – Definitions

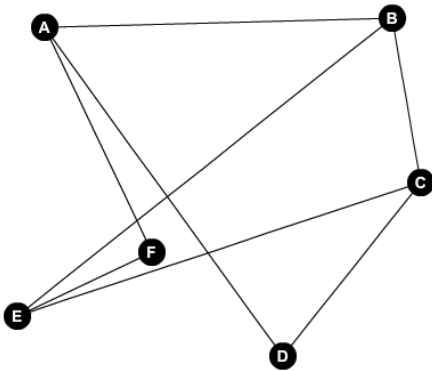
3.2 MORE GRAPH THEORY DEFINITIONS



- A _____ on a graph is how we can get from one vertex to another. Vertices and edges can be repeated. On the graph above, an example of a path is
- A _____ is a path where no edges are repeated (vertices can be repeated). On the graph above, an example of a simple path is
- The _____ of a path is the number of edges it contains. On the graph above, the length of path ABCDEBAC is
On the graph above, the length of path CBEDCA is
- The _____ between two vertices is the length of the shortest path joining the vertices. On the graph above, $d(A, E)$ is
On the graph above, $d(A, C)$ is

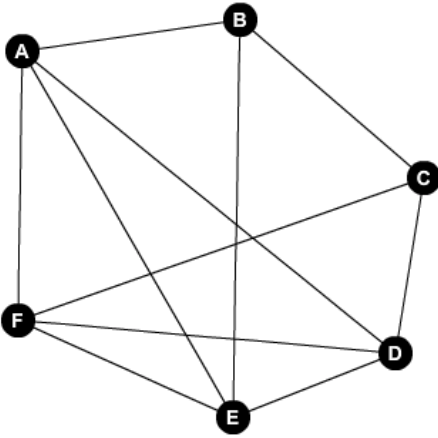
Try this question!

8) On the graph below:



- Name a path
- Name a simple path
- What is the length of path DABEFAB?
- Name a simple path with length 4
- What is the distance between C and A?
- What is the distance between A and D?

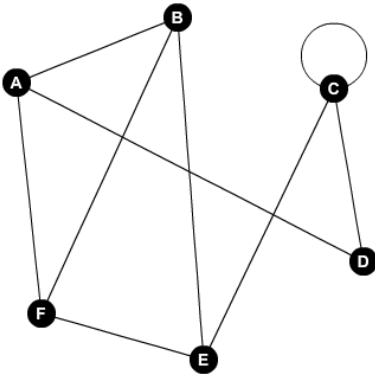
Graph Theory Unit – Definitions



- A _____ is a path that starts and ends at the same vertex.
On the graph above, an example of a circuit is
- A _____ is a circuit that has no repeated edges
(but it does not need to use every edge)
On the graph above, an example of a simple circuit is

Try this question!

9) On the graph below:



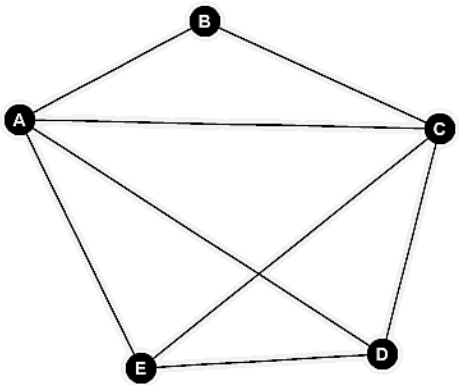
- find a path with length 4
- find a simple path with length 6
- find a circuit with length 5
- find a simple circuit with length 3
- find the distance between vertices A and C

Graph Theory Unit – Euler Path and Circuit

3.3 EULER PATH AND CIRCUIT

- An _____ (pronounced “oiler”) is a path that travels over every edge once and only once.
 - An Euler path exists if exactly 2 vertices have a degree that is an odd number (and the rest have a degree that is an even number).
 - The Euler path will start at one of the vertices with an odd degree and end at the other vertex with an odd degree.
 - An Euler path also exists if all vertices have a degree that is an even number (but this is a special case, called an Euler circuit – see below)

Ex: Find an Euler path in the graph below



Degree of Each Vertex: Based on the degree of each vertex, the Euler path must:

A:

B:

C:

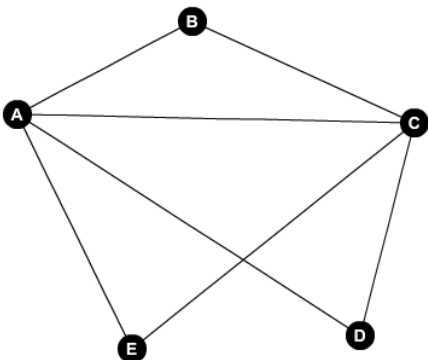
D:

E:

Ex:

- An _____ is a circuit that travels over every edge once and only once (it is an Euler path that starts and ends at the same vertex).
 - An Euler circuit is a special case of an Euler path. It is an Euler path that begins and ends at the same vertex.
 - An Euler circuit exists if all vertices have degrees that are even numbers.

Ex: Find an Euler circuit in the example below



Degree of Each Vertex:

A:

B:

C:

D:

E:

Based on the degree of each vertex, an Euler circuit does exist (in fact, there are many)

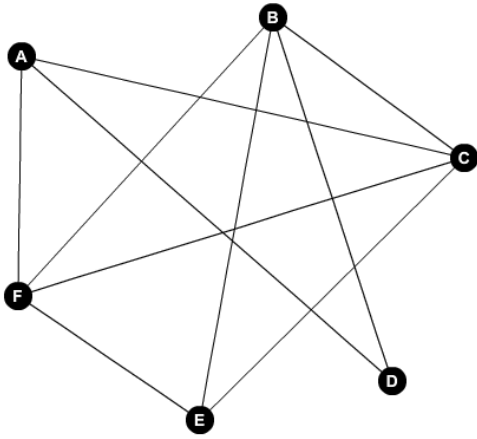
Ex:

Graph Theory Unit – Euler Path and Circuit

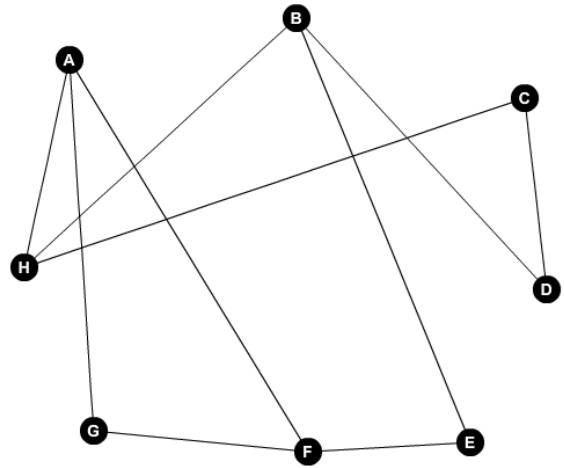
Try these questions!

10) Does an Euler path exist in the graphs below? If yes, identify one.

a)

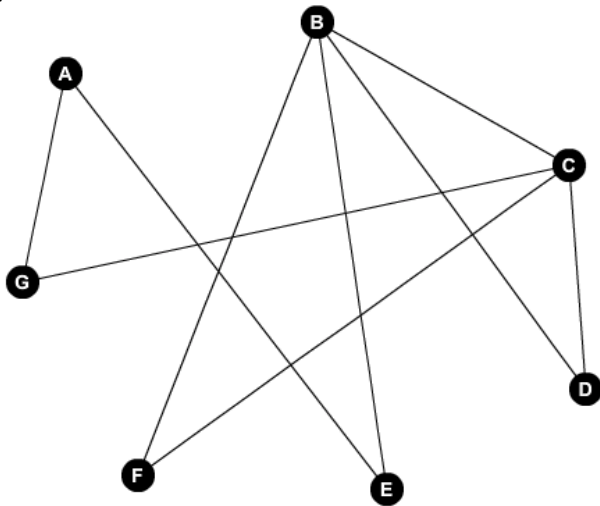


b)

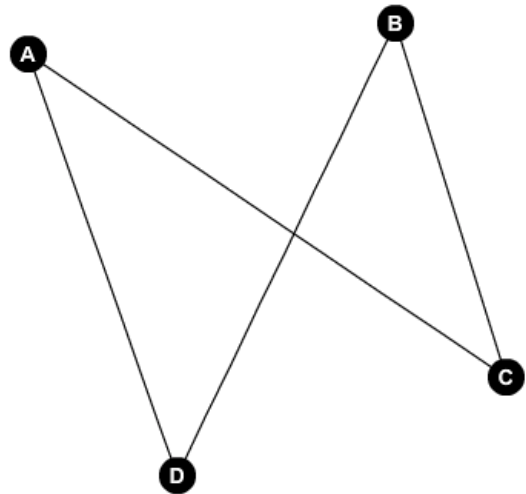


11) Does an Euler circuit exist in the graphs below? If yes, identify one.

a)



b)

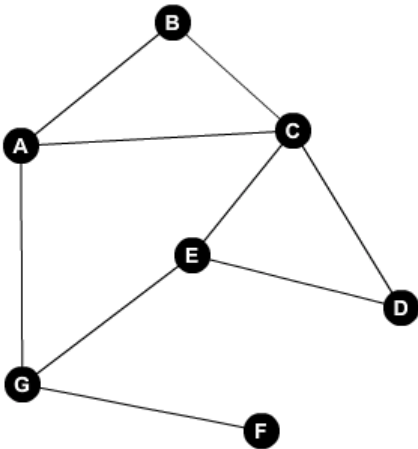


Graph Theory Unit – Hamiltonian Path and Circuit

3.4 HAMILTONIAN PATH AND CIRCUIT

- A _____ is a path that passes through every vertex once and only once (it does not need to include every edge).
 - There is no good way to determine whether a Hamiltonian path exists other than trying to find one.

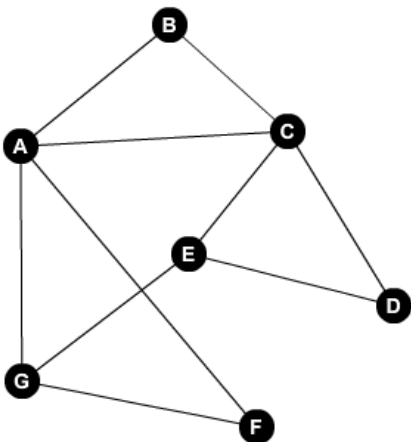
Ex: Find a Hamiltonian path in the graph below



A Hamiltonian path is

- A _____ is a Hamiltonian path that begins and ends at the same vertex (so the first vertex is repeated as the last vertex, but no other vertex is repeated and every other vertex is included).

Ex: Find a Hamiltonian circuit in the graph below

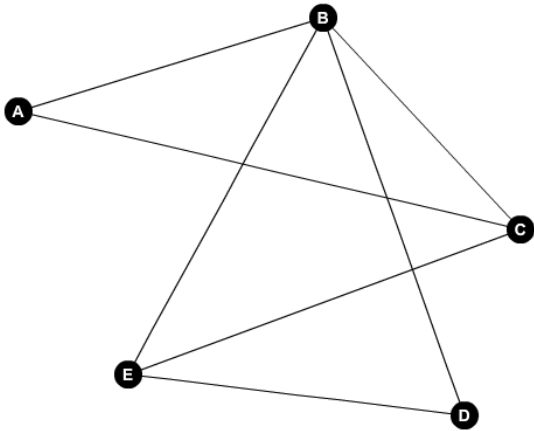


A Hamiltonian circuit is

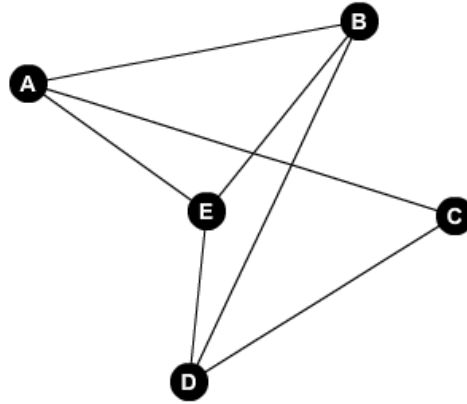
Graph Theory Unit – Hamiltonian Path and Circuit

Try these questions!

12) Identify a Hamiltonian path in the graph below.



13) Identify a Hamiltonian circuit in the graph below.



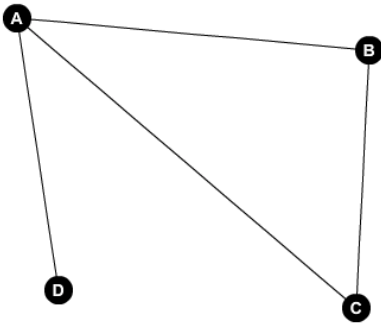
Practice Questions

14)

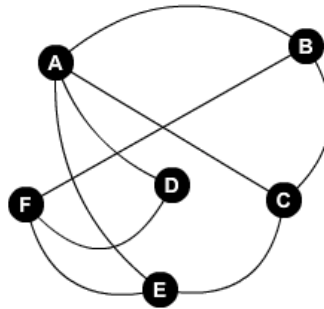
In each of the following graphs, indicate whether the following exist:

i) Euler path; ii) Euler circuit; iii) Hamiltonian path; iv) Hamiltonian circuit

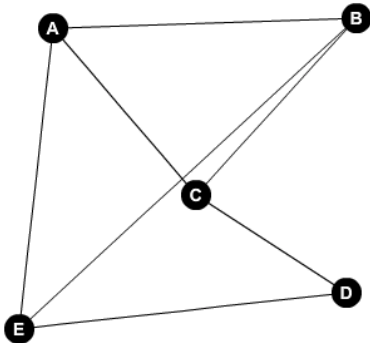
a)



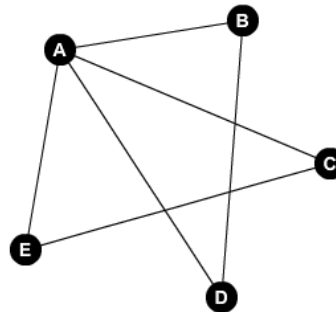
c)



b)



d)

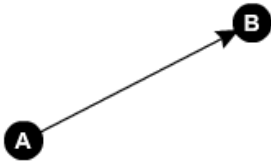


Graph Theory Unit – Directed Graphs

3.5 DIRECTED GRAPH

- A _____ has one or more directed edges.
- A _____ is like a one-way street – we can only move along that edge in one direction. It is represented with an arrow on the edge.

Ex:

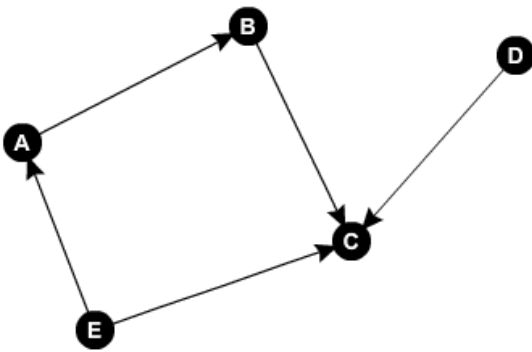


We can go from vertex A to vertex B, but not from vertex B to vertex A.

When we name directed edges, order matters.

This edge is AB (and not BA)

Ex:

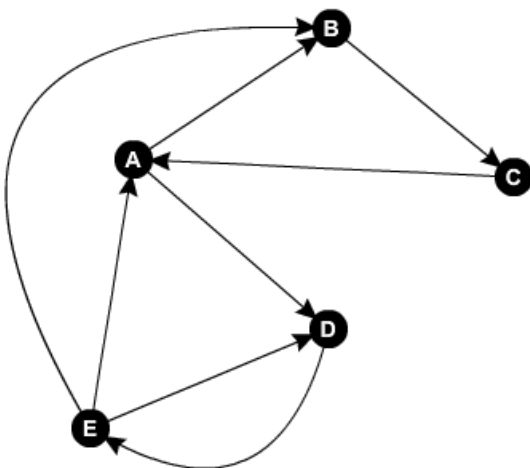


In this example, a path is ABC, but not ABCD.

This example does not have any circuits.

Practice Questions

15) In the graph below:



- Identify a path of length 4.
- Identify a simple circuit of length 3.
- Does path A-E-D exist? Explain.
- What is the length of path A-B-C-A-D-E?
- Determine $d(A, C)$.

Graph Theory Unit – Weighted Graphs

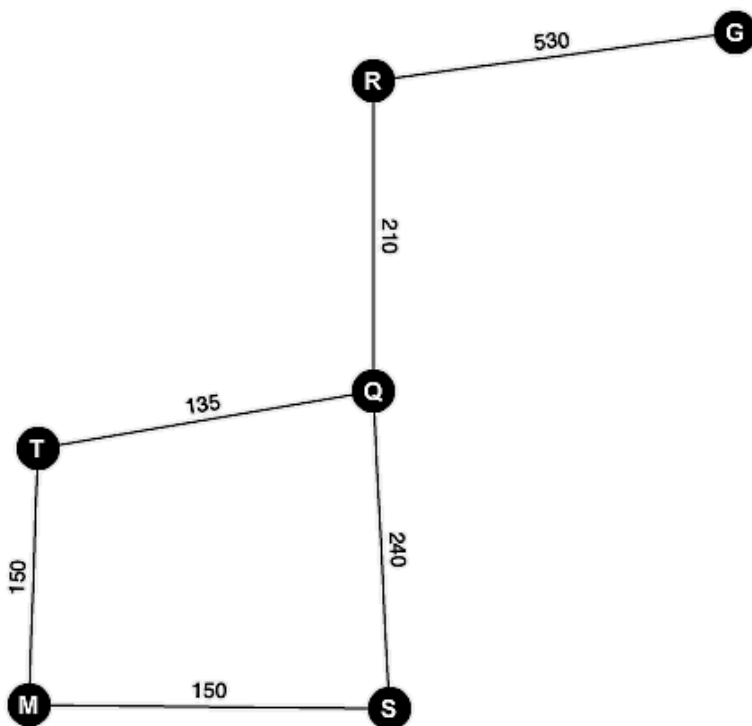
3.6 WEIGHTED GRAPHS (NETWORKS)

- A _____ is a graph in which every edge is assigned a weight.
- A _____ is a number, which could represent distance, time, etc.
- The _____ is found by adding the weights of all the edges included in the path.
- A weighted graph can be directed or not.

Ex: The network below shows the distance (in km) between towns linked by a rail network.

Transporting heavy equipment by train costs approximately \$100 per km.

Give the approximate cost of transporting heavy equipment from G to M if the train takes the shortest route.

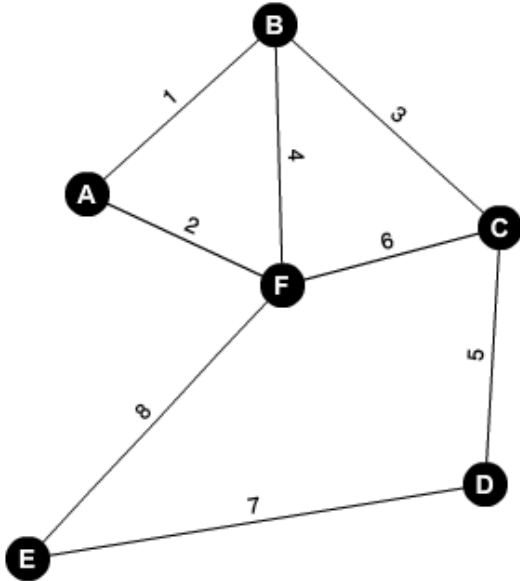


Options:

Graph Theory Unit – Weighted Graphs

Try this question!

16) Based on the graph below, determine:

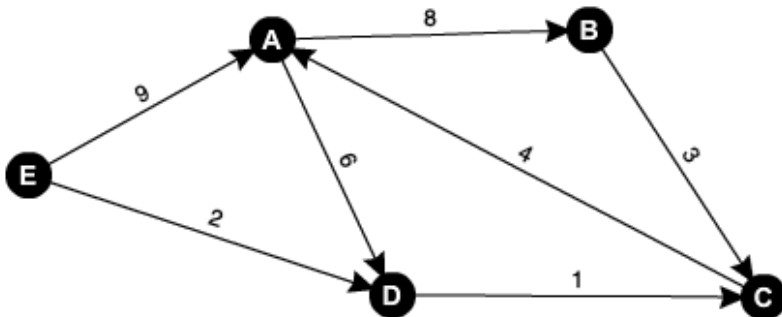


a) The weight of path A-B-C-F

b) The weight of circuit C-D-E-F-C

Practice Questions (directed and weighted)

17) The graph below is weighted and directed.



a) Determine the weight of path E-D-C-A-D

b) Determine the weight of path B-C-A-D

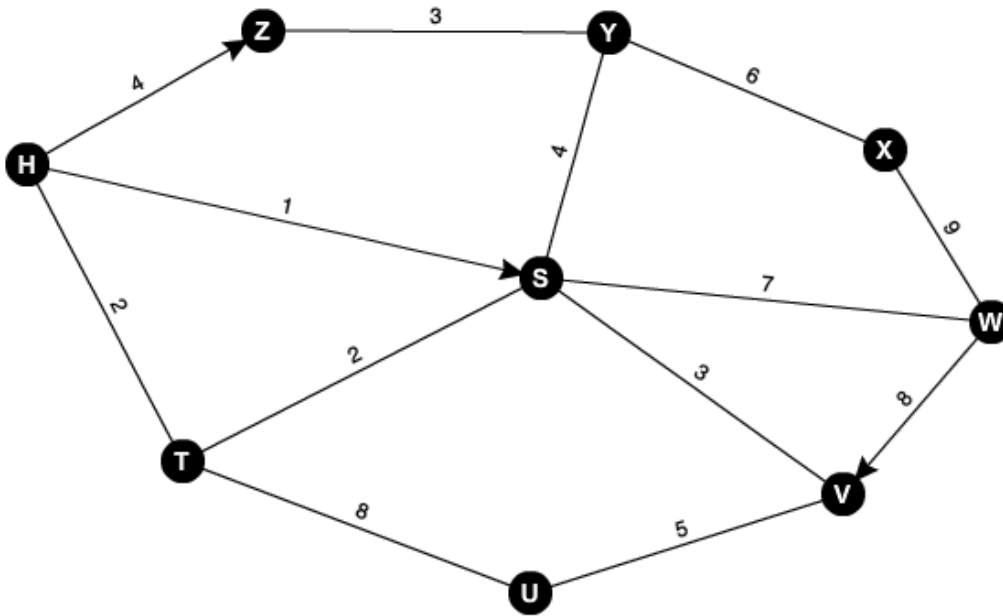
c) Determine the weight of path E-A-B-C

d) Identify all the simple paths going from vertex E to vertex B

e) Of the paths identified in part d, which one has the smallest weight?

Graph Theory Unit – Weighted Graphs

18) The following graph presents the length (in km) of various routes Louis could take as he trains for a marathon. He begins and ends each training session at his home, H.



a) For easy runs, Louis wants to run less than 10km without taking the same road twice. What route can he take and how long is his run?

b) How long is Louis's run if he takes the following route: H-Z-Y-S-V-U-T-H?

c) Louis would like to run a circuit that covers between 30 and 35 km without taking the same road twice. Is this possible (and if yes, what route could he take)?

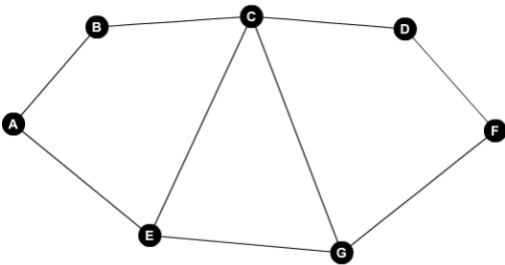
Graph Theory Unit – Path of Optimal Value

3.7 PATH OF OPTIMAL VALUE

- When we want to find the _____, we are looking for the longest or shortest path (the maximum or minimum, depending on the question) from one vertex to another.
 - On a graph without weighted edges, the _____ between two vertices corresponds to the path using the fewest edges between those vertices.
 - On a graph without weighted edges, the _____ between two vertices corresponds to the simple path (no repeated edges) using the most edges between those vertices.
 - On a weighted graph, the _____ between two vertices corresponds to the path that has the smallest weight between those vertices.
 - On a weighted graph, the _____ between two vertices corresponds to the simple path (no repeated edges) with the largest weight between those vertices.

In the graphs below, determine the path of minimum value and the path of maximum value with an initial vertex A and a final vertex F.

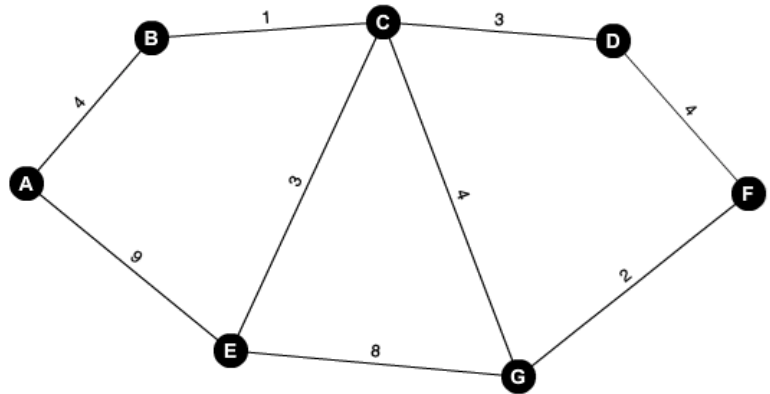
a)



Path of minimum value:

Path of maximum value:

b)



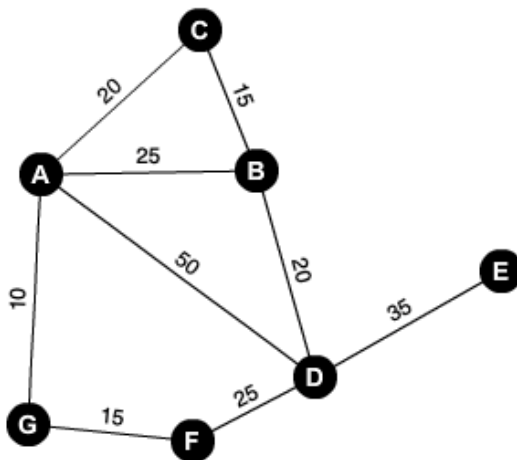
Path of minimum value:

Path of maximum value:

Graph Theory Unit – Path of Optimal Value

Try this question!

19) In the graph below, the values represent the amount (in thousands of dollars) that a construction company must pay to transport its equipment from one city to another.



a) Determine the minimum transport cost from City A to City E

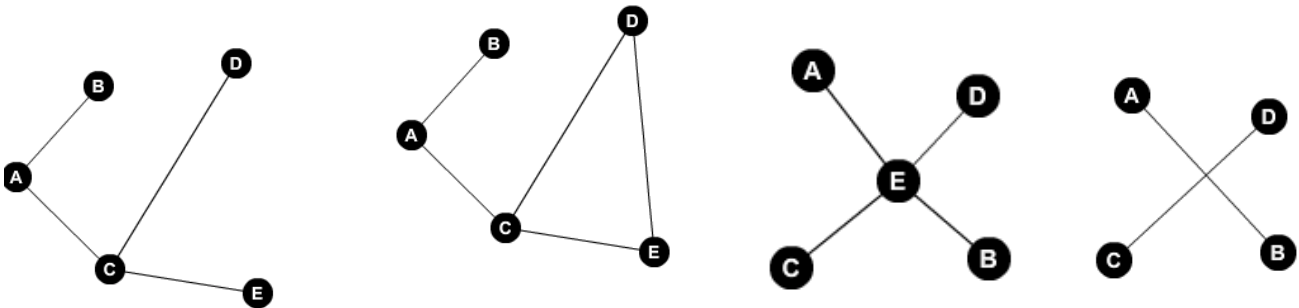
b) Determine the minimum transport cost from City G to City B

Graph Theory Unit – Tree of Optimal Value

3.8 TREE OF OPTIMAL VALUE

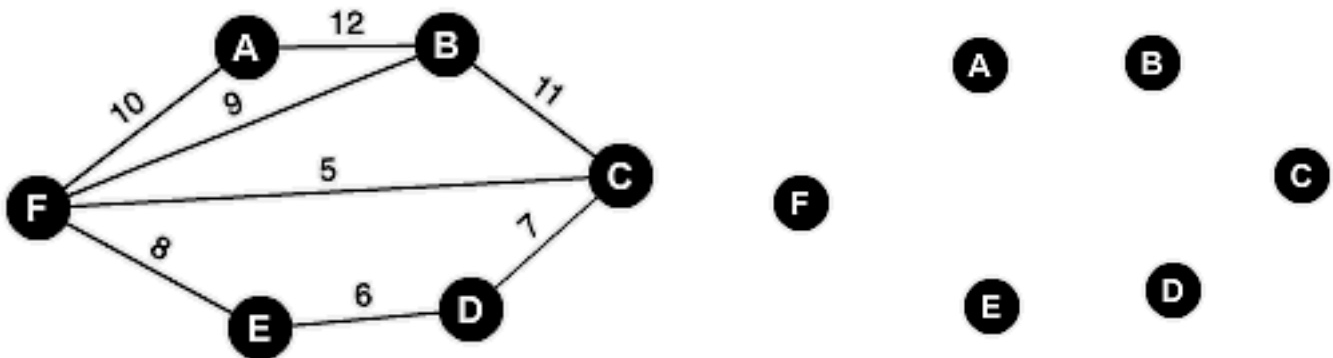
- A _____ is a connected graph with no simple circuits

Examples:



- A _____ selects only some edges in a graph such that all vertices are connected, there are no simple circuits, and we use either the largest or smallest weighted edges.
- There are several steps to creating a tree of optimal value. If we are looking for a tree of minimum value:
 - Copy the vertices of the graph
 - Select the edge with the lowest value and draw it.
 - Of the remaining edges, select the one with the lowest value and draw it.
 - Keep selecting the smallest edge and drawing it, unless an edge will create a simple circuit. Then skip that edge and move to the next one. Once you have created a tree, stop drawing edges.
- To create a tree of maximum value, follow the steps above, but use edges with the largest value.

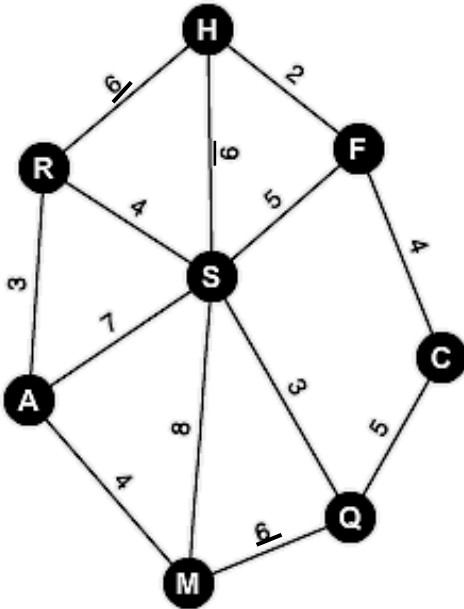
Ex: Create a tree of minimum value given the graph below



Graph Theory Unit – Tree of Optimal Value

Try these questions!

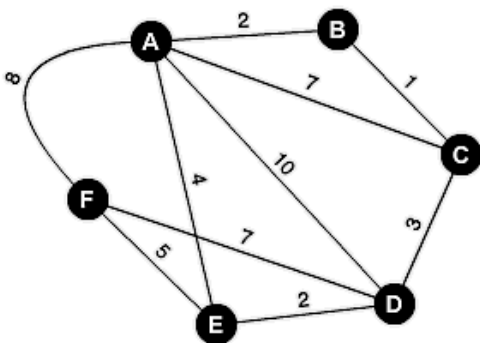
20) A hydroelectric dam generates electricity which is transmitted using high-tension lines to Quebec's main urban centers. These transmission lines lose some of their power as the electricity is being transmitted. The graph below shows some of these lines and the power loss in tens of megawatts. Vertex H is the hydroelectric dam.



The facility's engineering crew wants to minimize the power loss while connecting all the urban centers.

Which high-tension lines should be used and what is the total power loss?

21) A city park has developed a series of trails between various parking areas. In the winter, the city wants to maintain the fewest number of trails such that all parking areas are still connected, either directly or indirectly, but the total trail distance is maximized. The graph below represents the parking areas (vertices) and trails (edges) where the weight of each edge represents the length (in km) of that trail.

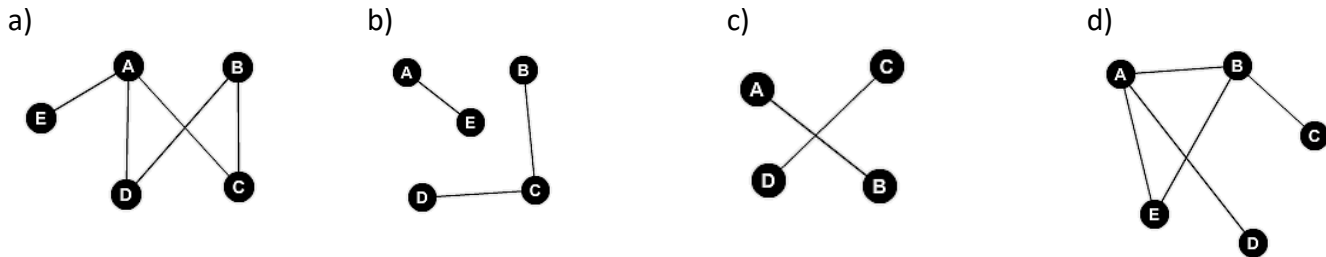


Which paths should the city maintain in the winter and what is the total distance of trails available?

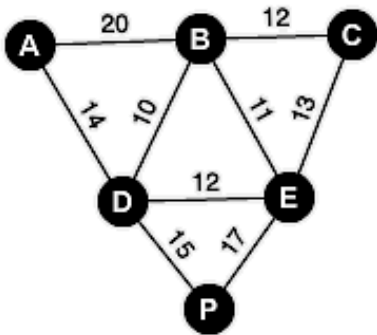
Graph Theory Unit – Tree of Optimal Value

Practice Questions

22) In the following graphs, what edge(s) would need to be added or removed in order for the graph to be a tree?

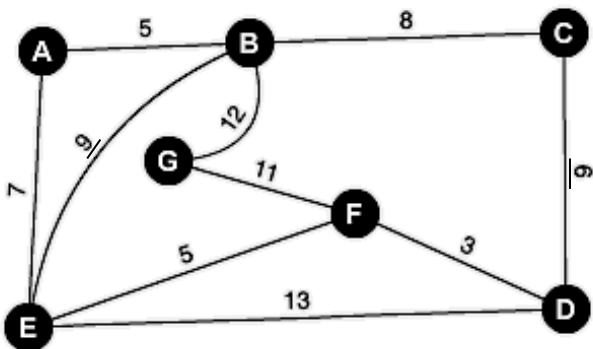


23) The sewage lines in a city need an upgrade and every neighborhood must be connected (either directly or indirectly) by sewage line to the purification plant, P. The graph below represents the neighborhoods in a city and the cost of upgrading the sewage lines (in thousands of \$).



What is the minimum cost for the city to upgrade the sewage lines?

24) The cost of hiring a taxi is based on the amount of time it takes to get from your starting place to your destination. The graph below represents a taxi ride’s travel time (in min) between intersections.



If a taxi costs \$1.50 per minute, calculate:

- a) The minimum cost to get from Point F to Point B
- b) The minimum cost to get from Point A to Point D

Graph Theory Unit – Critical Path

3.9 CRITICAL PATH

If we have many tasks that are necessary to complete a project, and some of the tasks can be carried out simultaneously, we can use graph theory to determine the minimum amount of time necessary to complete the project.

- A _____ (the minimum amount of time to complete all steps) is the simple path of ***maximum value***.

There are 5 keys to determining a critical path

1. Each vertex is a step in the project.
2. Each edge is weighted with the time it takes to complete the step (using the vertex at the start of the line) and each edge is directed.
3. Use the steps and time to create a graph.
4. Find all possible simple paths from the start of the project to the end.
5. Choose the *longest* path.

Ex: There are several steps required to launch a business. The following table lists the necessary steps, the time it takes to complete each step, and provides information on whether there are any steps that need to be completed before a step can begin.

| Step | Description | Execution Time (in days) | Prior Steps |
|------|--------------------------------------|--------------------------|-------------|
| A | Prepare a business plan | 30 | None |
| B | Conduct market research | 10 | A |
| C | Find partners | 25 | A |
| D | Find location | 20 | A |
| E | Analyze market research | 5 | B |
| F | Evaluate product-distribution system | 15 | C and D |
| G | Arrange financing | 35 | E and F |
| H | Launch company | None | G |

Determine the minimum time necessary to complete all the steps.

Graph Theory Unit – Critical Path

Try this question!

25) An accounting firm hires a company to review its computer system. The following is the company's proposal for the implementation of a new system.

| Step | Description | Execution Time (days) | Prior Steps |
|------|--|-----------------------|-------------|
| A | Analysis of needs | 10 | None |
| B | Detailed analysis of project | 8 | A |
| C | Purchase of computers | 21 | B |
| D | Training of programming team | 3 | B |
| E | Designing the accounting system | 6 | C |
| F | Coding the accounting system | 18 | C |
| G | Updating the computers | 5 | E and F |
| H | Installation and delivery of the computers and accounting system | 4 | D and G |
| I | End of computer work | None | H |

Determine the minimum amount of time necessary for the implementation of this new system.

Graph Theory Unit – Critical Path

Practice Questions

26) Tyson is having friends over for dinner. He start preparing the meal at 3:45 pm. The steps required for the dinner preparation are as follows:

| Step | Description | Execution time (min.) | Prior Steps |
|------|--|-----------------------|-------------|
| A | Choose the menu | 5 | None |
| B | Peel the carrots | 5 | A |
| C | Prepare the meatballs | 15 | A |
| D | Prepare the sauce | 5 | B |
| E | Cook the meatballs in the sauce with the carrots | 45 | C and D |
| F | Prepare the salad | 10 | D |
| G | Prepare the appetizer | 15 | C |
| H | Cook the appetizer | 15 | G |
| I | Prepare the dessert | 20 | G |
| J | Set the table | 10 | E and F |
| K | Serve dinner | 5 | H, I, J |
| L | End of preparation | None | K |

Tyson would like to complete all the steps by 5:00pm. Is this possible? Explain.

27) The process of writing, giving, and analysing tests teachers give to a class requires several steps, some of which can be carried out simultaneously. The steps required are as follows:

| Step | Description | Time (days) | Prior Steps |
|------|-----------------------------|-------------|-------------|
| A | Review the material | 1 | None |
| B | Decide on structure of exam | 1 | None |
| C | Write the questions | 5 | A and B |
| D | Review the questions | 2 | C |
| E | Write the exam | 1 | D |
| F | Check the exam | 1 | E |
| G | Give the exam | 1 | F |
| H | Correct the exam | 2 | G |
| I | Analyse the results | 1 | G |
| J | End of task | None | H and I |

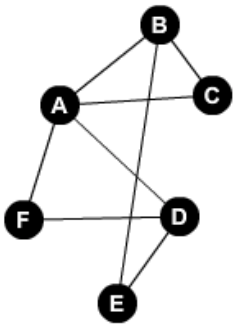
What is the minimum amount of time necessary to complete this project?

Graph Theory Unit – Chromatic Number

3.10 CHROMATIC NUMBER

- The _____ of a graph is the fewest number of colors required to color all the vertices of a graph while making sure no two adjacent vertices (vertices directly connected to one another) are the same color.
- Chromatic number can be used to:
 - Categorize information into as few groups as possible (ex: the number of colors required to color a map so that no countries sharing a border are the same color).
 - Categorize or group data based on incompatibilities (ex: making groups so that people who do not work well together are in different groups).
- There are 4 steps to determining the chromatic number of a graph
 1. Find the vertex with the highest degree and color it (if there is a tie, start with either)
 2. Find the vertices adjacent to the one you colored. Starting with the highest degree of those, color them a different color than the first vertex. Use the same color for all, unless they are adjacent. Use as few colors as possible.
 3. Of the remaining vertices, start with the highest degree and color is so that it is not the same color as any vertex it is adjacent to, using colors already used, if possible.
 4. The number of colors used is the chromatic number

Ex: Find the chromatic number of the graph below



Ex: You are the team leader and have a group of 5 people. You want to make small groups to complete a task. It does not matter if the groups are the same size, but you must make sure people who do not work well together are in different groups.

- Beth cannot work with Sue
- David and Jonas argue so will not get any work done
- Sue and Brian are unproductive together
- David and Sue are poorly matched
- Brian and David are not compatible

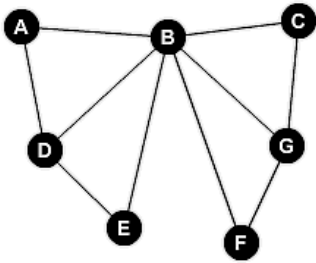
What is the fewest number of groups you can make?

Graph Theory Unit – Chromatic Number

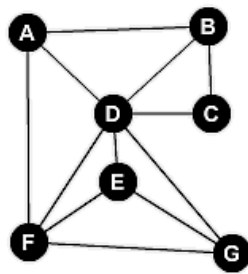
Try this question!

28) Determine the chromatic number for the graphs below.

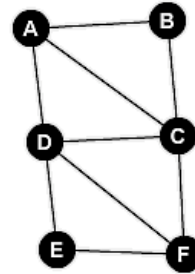
a)



b)



c)



Practice Questions

29) Lydia has to color the map of South America for her geography class. The teacher has asked students not to use the same color for two countries that share a common border. Lydia only has 4 colors she can use and she wants to know if she can complete this task.

Using the map:

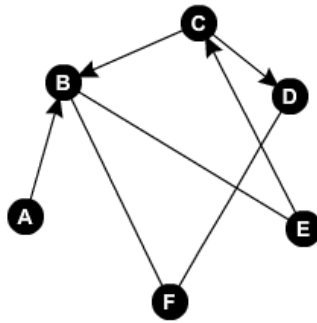
- Construct a graph (vertices are the countries and edges represent the countries that share a common border).
- Determine the chromatic number
- Can Lydia complete the task?



Graph Theory Unit – Exam Style Questions

Exam Style Questions

30) Consider the graph below.



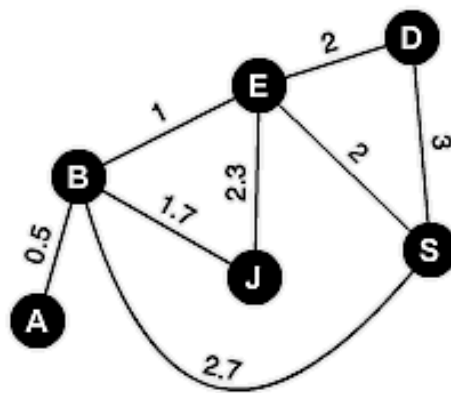
Which of the following does this graph contain?

- A) Euler Path
- B) Euler Circuit
- C) Hamiltonian Path
- D) Hamiltonian Circuit

31) Emily (E), Jake (J), Sevanna (S), and Durham (D) are sharing a taxi to the airport (A). Vertex B is an intersection.

The taxi will start at Emily’s house and then will pick up Jake and Sevanna in any order. They will then drive to pick up Durham before heading to the airport.

The graph below represents a map of the possible routes the taxi can take with the weights representing the distance (in km). The taxi can use the same edge more than one.



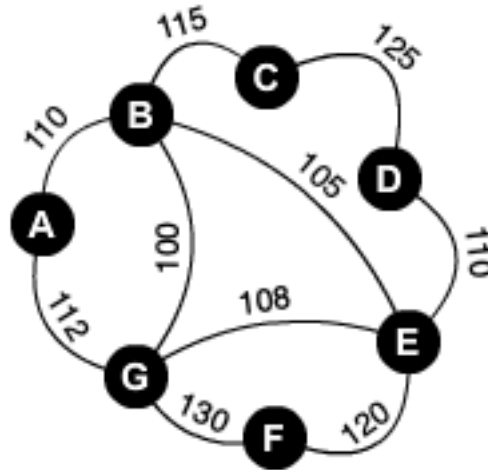
What is the length of the shortest route the taxi can take?

- A) 10.5 km
- B) 12.6 km
- C) 13.1 km
- D) 14.1 km

Graph Theory Unit – Exam Style Questions

32) Roger wants to install a watering system in his garden. On the graph below:

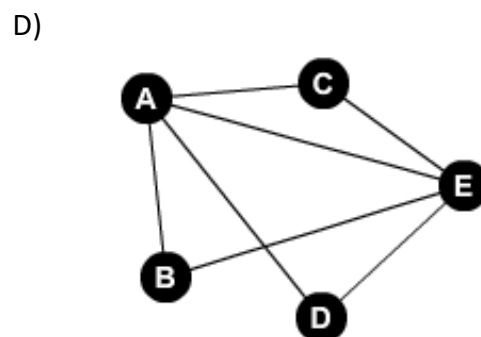
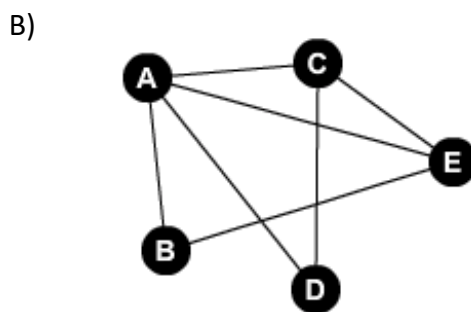
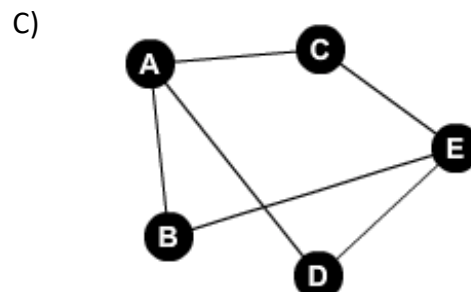
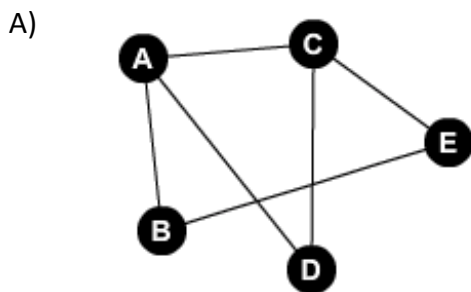
- The sprinklers are represented by vertices A, B, C, D, E, F, and G.
- The pipes connecting the sprinklers are represented by the edges.
- The number associated with each edge represents the cost of installation, in dollars.



What is the lowest cost to connect all the sprinklers while minimizing the cost?

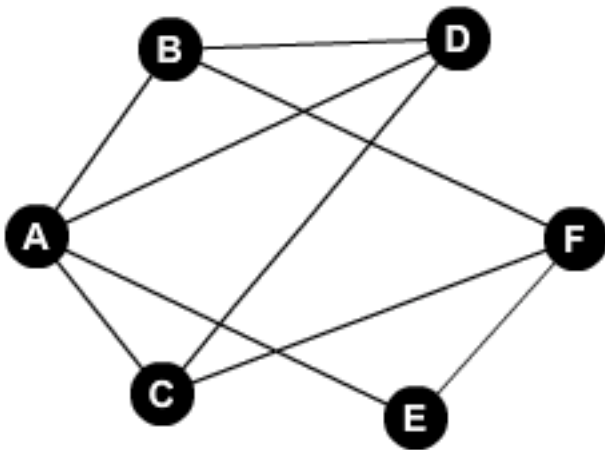
- A) \$313 C) \$822
 B) \$660 D) \$880

33) Which of the following graphs contains an Euler circuit?



Graph Theory Unit – Exam Style Questions

34) What is the chromatic number for the graph below?



- A) 2 C) 4
 B) 3 D) 5

35) Ms. James is dividing her class into groups and she wants to make sure all students in a group work well together. Ms. James wants to create the fewest number of groups and wants to make sure every student is in a group with at least one other student.

The table below contains information about students who do not work well together.

| Student | Is incompatible with... |
|---------|-------------------------|
| Amanda | Chris, David, Francis |
| Bob | David, Francis |
| Chris | Amanda, Eli, Francis |
| David | Amanda, Bob |
| Eli | Chris, Francis |
| Francis | Amanda, Bob, Chris, Eli |

What is the fewest number of groups Ms. James can make and which students are grouped together?

Graph Theory Unit – Exam Style Questions

36) Sierra is preparing a dinner for her friends. The following table shows the different steps involved in preparing and serving the dinner.

| Tasks | Time (min.) | Prerequisite |
|---|-------------|--------------|
| A. Mix brownies | 15 min. | none |
| B. Bake brownies | 45 min. | A |
| C. Chop the vegetables | 10 min. | none |
| D. Season the vegetables | 5 min. | C |
| E. Prepare the chicken | 15 min. | none |
| F. Cook the chicken | 90 min. | E |
| G. Peel the potatoes | 10 min. | none |
| H. Boil the potatoes | 15 min. | G |
| I. Mash the potatoes | 5 min. | H |
| J. Remove the chicken from oven to cool | 10 min. | F |
| K. Roast the vegetables | 15 min. | D, J |
| L. Serve the meal | None | B, I, K |

What is the minimum amount of time Sierra needs to prepare and serve the dinner?

37) A company has taken on a new project and the table below shows the steps necessary to complete this project.

| Tasks | Time (days) | Prerequisite |
|-------|-------------|--------------|
| A. | 4 | none |
| B. | 5 | A |
| C. | 6 | A |
| D. | 4 | B |
| E. | 10 | B |
| F. | 3 | D |
| G. | 5 | C |
| H. | 10 | E, F, G |
| I. | none | H |

The company has enough money to hire one extra person to help with these project.

Option 1: Hire someone to help with task C, which would reduce the time it takes to complete task C by 5 days

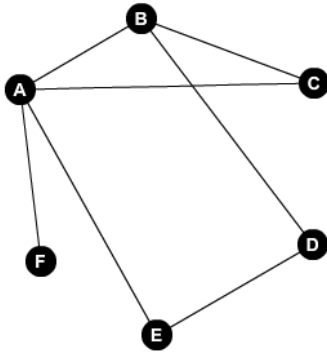
Option 2: Hire someone to help with task E, which would reduce the time it takes to complete task E by 4 days

Given the company wants to complete this project in as little time as possible, should they choose option 1 or option 2, and how much time will be save

Graph Theory Unit – Answer Key

ANSWER KEY

1) (the graph below is one example of a correct answer)



2)

Vertices (and degree of each): A – degree 2, B – degree 2, C – degree 3, D – degree 3, E – degree 2

Edges: AB, AC, BD, CD, CE, DE

Order: 5

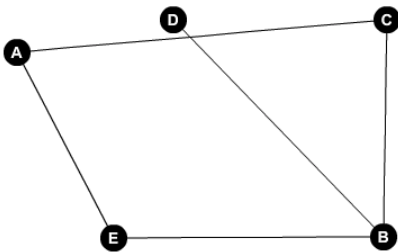
3)

Loop(s): EE

Parallel Edge(s): CD(1) and CD(2); BD(1) and BD(2)

4a) Neither 3b) Connected 3c) Complete (and connected)

5)



6)

a) A – 2; B – 3; C – 3;
D – 2; E – 2; F – 2

b) AB, AD, BE(1), BE(2), CC, CF, DF c) 6

d) CC

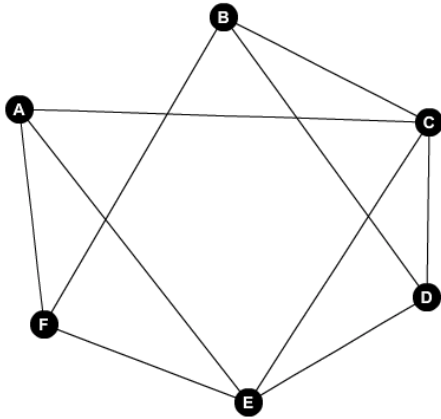
e) BE(1), BE(2)

f) yes

g) no

Graph Theory Unit – Answer Key

h)



7)

a) A – 1; B – 4; C – 4;
D – 2; E – 1; F – 2

b) AE, BC(1), BC(2), BD, BF, CD, CF c) 6

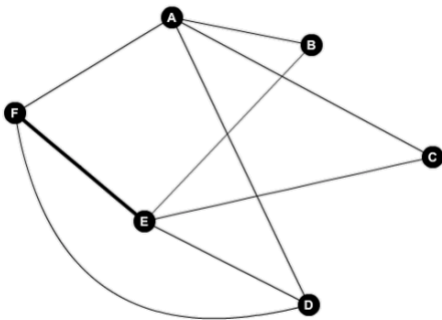
d) none

e) BC(1), BC(2)

f) no

g) no

h)



8)

a) many possible solutions

b) many possible solutions

c) length is 7

d) many possible solutions

e) $d(C, A) = 2$

f) $d(A, D) = 1$

9)

a) multiple options

b) multiple options

c) multiple options

d) multiple options

e) $d(A, C) = 2$

10)

a)
Yes, an Euler path exists (it must start at A and end at E)
many options

b)
No, an Euler path does not exist.

Graph Theory Unit – Answer Key

11)

a)
Yes, an Euler circuit does exist.
Many options

b)
Yes, an Euler circuit does exist.
Many options

12) Many options

13) Many options

14)

a) Euler path, Hamiltonian path

c) Hamiltonian path, Hamiltonian circuit

b) Hamiltonian path, Hamiltonian circuit

d) Euler path, Euler circuit, Hamiltonian path

15) a) Many options
d) 5

b) Many options
e) 2

c) no (cannot go from A to E)

16) a) 10

b) 26

17) a) 13
c) 20

b) 13
d) E-D-C-A-B; E-A-D-C-A-B; E-A-B e) E-D-C-A-B

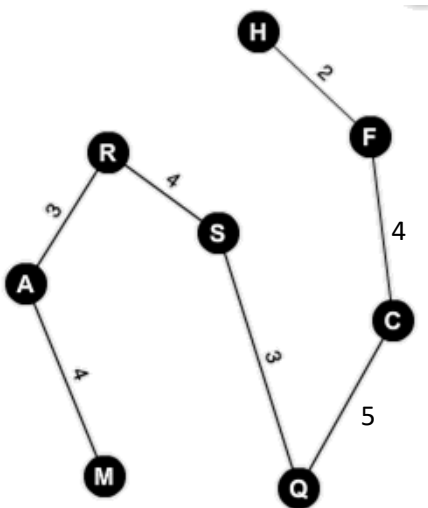
18) a) Many options
c) Many options

b) 29 km

19) a) 80

b) 35

20)

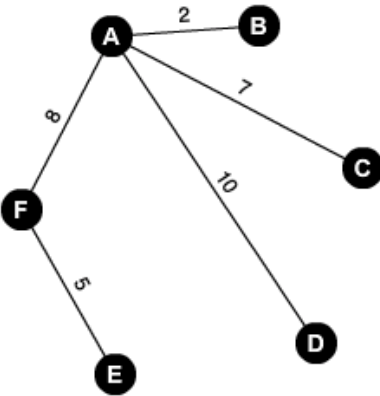


or same graph but not QC and add SF

Total power loss is 25 (or 250 megawatts)

Graph Theory Unit – Answer Key

21)



32 km

- 22) a) remove one of the following: AC, BC, BD, or AD
b) add one of the following: AD, AC, AB, ED, EC, or EB
c) add one of the following: AC, AD, BC, or BD
d) remove one of the following: AB, AE, or BE

23) \$62 000.00

- 24) a) \$25.50
b) \$28.50

25) 66 days

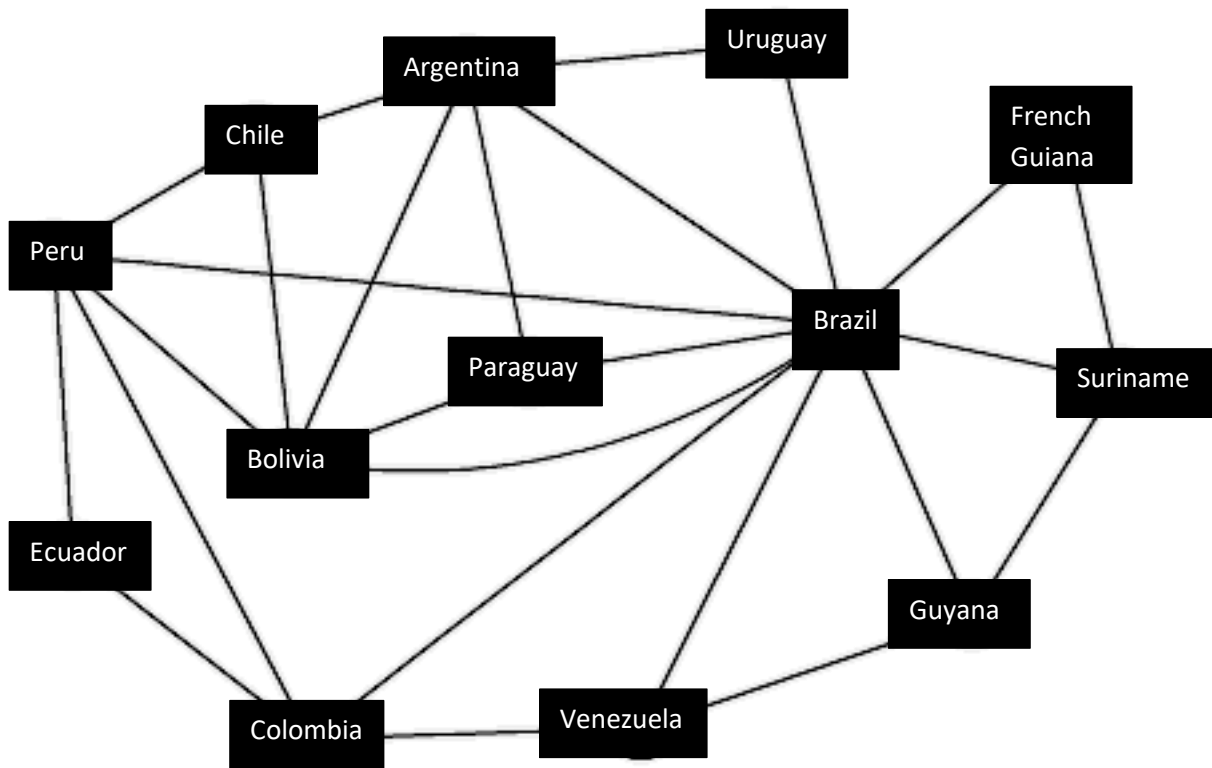
26) He does not have enough time (he needs 80 minutes but only has 75)

27) 13 days

- 28) a) 3 b) 4 c) 3

Graph Theory Unit – Answer Key

29) a)



b) 4

c) yes

30) C – Hamiltonian Path

31) C – 13.1 km

32) B – \$660

33) D

34) B – 3

35) 3 groups: Amanda and Eli; Bob and Chris; David and Francis

36) 130 minutes

37) Option 2. It will save the company 3 days.