For these questions, use the simulation "Quantum key distribution (BB84 protocol) with spin 1/2 particles" in the QuVis HTML5 collection.
www.st-andrews.ac.uk/physics/quvis/simulations_html5/sims/cryptography-bb84/Quantum_Cryptography.html

1) Have a play with the simulation for a few minutes getting to understand the controls and displays before answering these questions.

2) a) If Alice sends a single particle with a spin state of $|+\rangle$ and Bob measures with his Stern-Gerlach apparatus (SGA) oriented along Z, what is the probability that Bob will measure +1 (a positive deflection along Z)? Explain your answer.

b) The first column of the table below refers to Bob's SGA orientation, the second to his measurement outcome. Complete the third column, namely what Bob can infer about the spin state that Alice sent without knowing her basis (X or Z).

Bob's SGA orientation	Bob's measurement	What Bob can infer about the spin state Alice sent without knowing her basis
Z	1	
Z	0	
X	1	
X	0	

c) In the "key generation" panel, under what condition is a key bit generated? Explain why this is the case using your table from part b). What determines the key bit value?

3) Set up the simulation so that **Eve is eavesdropping** and **fixed orientations** are used. In the simulation, it is assumed that by chance Eve chooses the same basis as Bob for her measurements if fixed orientations are used.

a) Assume Eve's SGA in front of her detector was oriented along Z. What state does Eve resend to Bob if she i) measured 1; ii) measured 0?

b) Do errors occur in Alice and Bob's measurements when Eve intercepts and resends particles? Is the key secure using only a single basis?

4) Set up the simulation so that there is **no eavesdropper** and **random orientations** are used. What fraction of Alice's particles lead to a key bit? Explain how this fraction comes about.

5) Set up the simulation so that **Eve is eavesdropping** and **random orientations** are used.

a) Explain how Eve intercepts particles and what state she resends to Bob.

b) Explain using a specific example from the simulation how an error occurs in Alice and Bob's measurement when Eve intercepts and resends particles. What can you say about Eve's basis when an error occurs?

c) Assume Alice and Bob have chosen the *same* basis. Does an error occur every time Eve chooses the wrong basis (a different one to Alice and Bob)? Explain.

d) What fraction of key bits lead to an error? Explain how this fraction comes about.

e) What actions do Alice and Bob take to determine whether or not Eve has compromised the security of their key?

6) Which of the Challenges did you find most difficult and why? Explain what this challenge is about and how you solved the challenge, including your calculation or reasoning.