1. Crossing over in meiosis I is required for homologous chromosomes to properly align during metaphase and segregate during the first cell division.

(a)

(i) **Describe** the function of S phase of interphase.

Some regions of a chromosome called hotspots display a higher frequency of crossing over than other regions do. Crossing over is suppressed in chromosomal regions near the centromeres. The centromere region of a duplicated chromosome includes a collection of proteins that form a structure called the kinetochore. Scientists hypothesized that one or more of these kinetochore proteins are responsible for suppressing crossing over around the centromere.

To investigate their hypothesis, scientists modified chromosome 8 in yeast such that, in each cell, one chromosome from the pair of homologous chromosome 8s contained the gene encoding red fluorescent protein (RFP), while the other chromosome from the pair contained the gene encoding green fluorescent protein (GFP). Cells expressing RFP emit (give off) red light, and cells expressing GFP emit green light. Models of the modified chromosome 8 both before and after crossing over are shown in Figure 1.

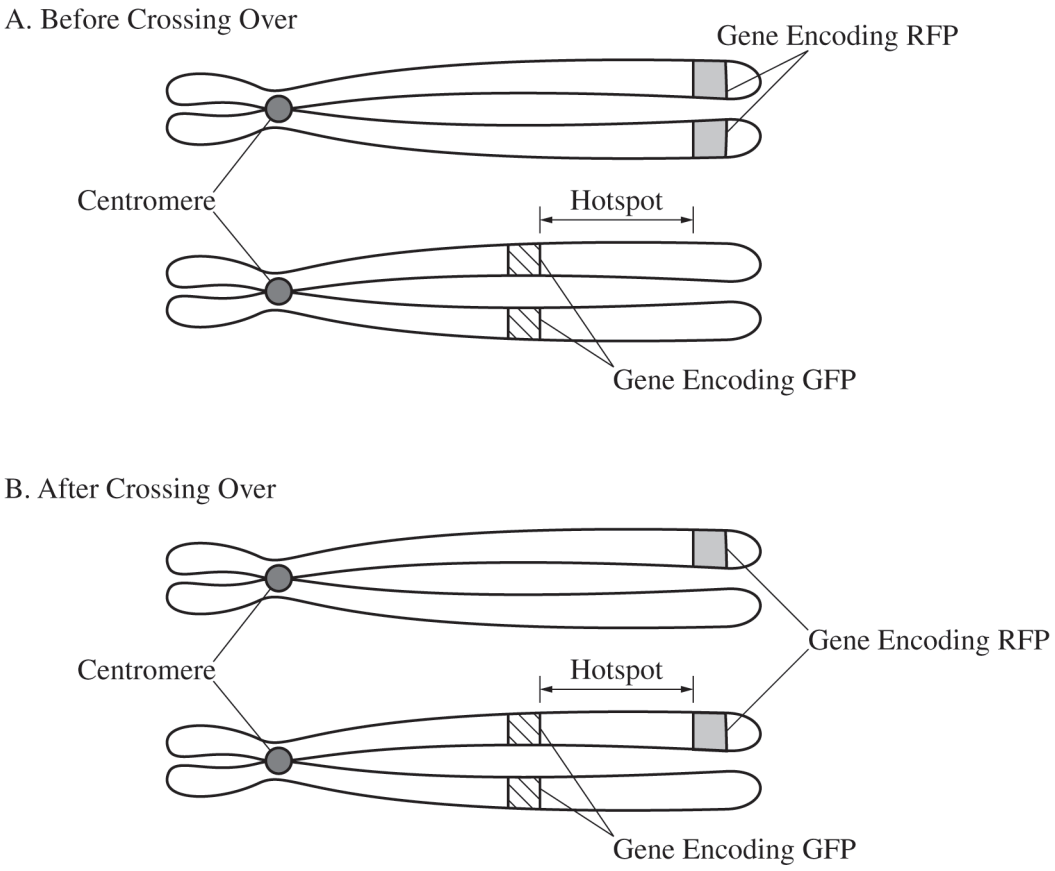

Figure 1. Models of modified chromosome 8 used in the experiment (A) before and (B) after crossing over occurs at the hotspot

(ii) **Explain** why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker.

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The scientists then investigated whether attaching individual kinetochore proteins to a specific DNA sequence present in a known crossing-over hotspot on chromosome 8 affected the frequency of crossing over at this location. In their first experiment, they examined three groups of yeast cells containing the modified chromosome 8. Group 1 contained no kinetochore proteins attached to the hotspot, group 2 contained the kinetochore protein CTF attached to the hotspot, and group 3 contained the kinetochore protein IML attached to the hotspot. For each group, the scientists determined the frequency of crossing over between the RFP and GFP genes. To determine the frequency, the scientists added the number of cells emitting both red and green light to the number of cells that emitted no light and divided by the total number of cells (Figure 2).

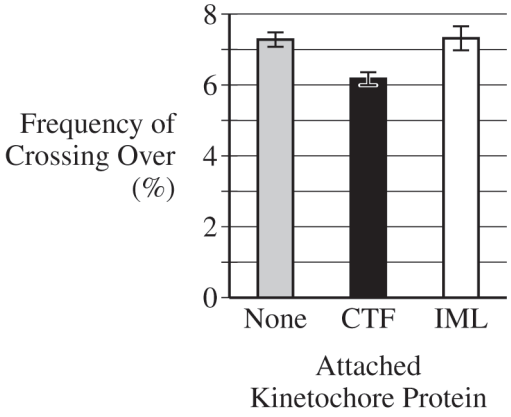

Figure 2. The frequency of crossing over in a hotspot on yeast chromosome 8 for cell groups treated with different kinetochore proteins. Error bars represent $\pm 2SE_{\bar{x}}$.

(b)

(i) **Identify** the control group for the scientists' first experiment, shown in Figure 2.

(ii) In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control.

(iii) **Identify** the independent variable in the follow-up experiment.

(c) Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot.

(d)

(i) **Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot.

(ii) Provide reasoning to **justify** your prediction.

(iii) **Explain** how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures.

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Question 1: Interpreting and Evaluating Experimental Results with Experimental Design — 9 points

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To investigate their hypothesis, scientists modified chromosome 8 in yeast such that, in each cell, one chromosome from the pair of homologous chromosome 8s contained the gene encoding red fluorescent protein (RFP), while the other chromosome from the pair contained the gene encoding green fluorescent protein (GFP). Cells expressing RFP emit (give off) red light, and cells expressing GFP emit green light. Models of the modified chromosome 8 both before and after crossing over are shown in Figure 1.

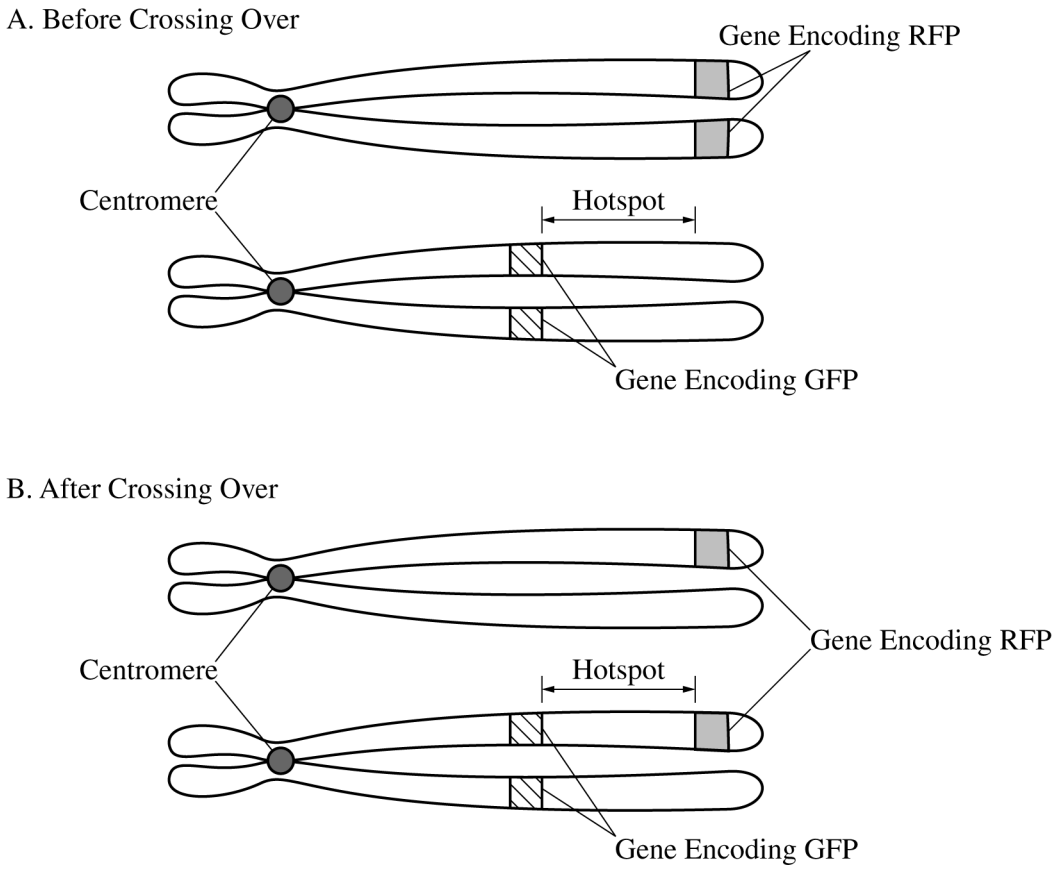

Figure 1. Models of modified chromosome 8 used in the experiment (A) before and (B) after crossing over occurs at the hotspot

The scientists then investigated whether attaching individual kinetochore proteins to a specific DNA sequence present in a known crossing-over hotspot on chromosome 8 affected the frequency of crossing

over at this location. In their first experiment, they examined three groups of yeast cells containing the modified chromosome 8. Group 1 contained no kinetochore proteins attached to the hotspot, group 2 contained the kinetochore protein CTF attached to the hotspot, and group 3 contained the kinetochore protein IML attached to the hotspot. For each group, the scientists determined the frequency of crossing over between the RFP and GFP genes. To determine the frequency, the scientists added the number of cells emitting both red and green light to the number of cells that emitted no light and divided by the total number of cells (Figure 2).

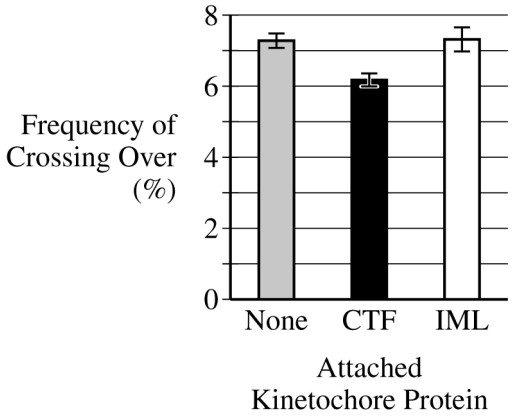

Figure 2. The frequency of crossing over in a hotspot on yeast chromosome 8 for cell groups treated with different kinetochore proteins. Error bars represent $\pm 2\mathrm{SE}_{\bar{X}}$.

(a)	**Describe** the function of S phase of interphase. Accept one of the following: • (The function of S phase is to) replicate/duplicate/synthesize the DNA/chromosomes. • (The function of S phase is to) double the amount of DNA.	**1 point**
	Explain why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker. Accept one of the following: • Some cells will receive a chromosome/(sister) chromatid that did not undergo crossing over/recombination (in the hotspot). • Two (or a multiple of two) crossing-over events occurred (in the hotspot). • Each daughter cell will receive one of the four sister chromatids. Two of the sister chromatids shown in Figure 1 have only one fluorescent protein gene. • The two chromosomes that were not involved in crossing over will have only the RFP gene or the GFP gene. After meiosis II, a gamete with one of these chromosomes will have only the RFP or the GFP gene.	**1 point**
		Total for part (a) 2 points
(b)	**Identify** the control group for the scientists' first experiment, shown in Figure 2. Accept one of the following: • Group 1 • (The group called) None • Cells with no (kinetochore) protein (attached to the chromosome)	**1 point**

	In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control. Accept one of the following: • (Using a modified CTF enabled the scientists) to determine whether DNA binding of the CTF/kinetochore protein affects/inhibits crossing over/recombination. • (Using a modified CTF enabled the scientists) to determine whether just the presence of the CTF/kinetochore protein is enough to affect/inhibit the crossing over/recombination frequency.	**1 point**
	Identify the independent variable in the follow-up experiment. Accept one of the following: • The type of CTF used • The presence or absence of (modified/unmodified) CTF	**1 point**
		Total for part (b) 3 points
(c)	Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot. Accept one of the following: • CTF attachment results in a decreased/lower frequency of crossing over/recombination, (whereas IML had no effect). • IML attachment results in an increased/a higher frequency of crossing over/recombination (compared with CTF attachment).	**1 point**
(d)	**Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot. Accept one of the following: • There will be zero/two (copies). • There will be one less/one extra (copy).	**1 point**
	Provide reasoning to **justify** your prediction. • Cells (with attached CTF molecules) undergo crossing over/recombination at a lower frequency, so it is more likely that nondisjunction would occur/chromosomes would not separate properly.	**1 point**
	Explain how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures. • Hotspots would increase genetic diversity; therefore, it would be more likely that some individuals would survive and reproduce.	**1 point**
		Total for part (d) 3 points
		Total for question 1 9 points