Problem with chromosome theory:

There are more genes than chromosomes
Sex linkage

Fly room at Columbia ~1920

The white-eyed male, bred to his red-eyed sisters, produced 1,237 red-eyed offspring, \(F_1\), and 3 white-eyed males. The occurrence of these three white-eyed males \(F_1\) (due evidently to further sporting) will, in the present communication, be ignored.

The \(F_1\) hybrids, inbred, produced:

- 2,459 red-eyed females,
- 1,011 red-eyed males,
- 782 white-eyed males.

No white-eyed females appeared. The new character showed itself therefore to be sex limited in the sense that it was transmitted only to the grandsons. But that the character is not incompatible with femaleness is shown by the following experiment.

The white-eyed male (mutant) was later crossed with some of his daughters \(F_1\), and produced:

- 129 red-eyed females,
- 132 red-eyed males,
- 88 white-eyed females,
- 86 white-eyed males.

Morgan, 1910
Sex linkage

P

RX

F1

RX

WX

Meredith, Sturtevant, Muller, Bridges, 1915
Crossing over

**P**
- ♀ white Normal Wing ×
- ♂ Red rudimentary

**F1**
- ♀ Red Normal Wing ×
- ♀ white Normal Wing

**F2**
- ♀ white Normal Wing 520
- ♀ Red Normal Wing 480
- ♂ Red Normal Wing 160
- ♂ Red rudimentary 368
- ♂ white Normal Wing 402
- ♂ white rudimentary 170
Three-factor cross/ crossover interference

\[ P \quad \frac{ywr}{ywr} \times \frac{+++}{+++} \]

\[ F1 \quad \frac{YWR}{ywr} \times \frac{ywr}{ywr} \]

\[ F2 \quad ywr \quad 6972 \quad NCO \]

\[ YWR \quad 60 \quad SCO \]

\[ Ywr \quad 60 \quad SCO \]

\[ YWr \quad 3454 \quad SCO \]

\[ ywR \quad 9 \quad DCO \]

\[ yWR \quad \]

\[ YwR \quad \]

\[ \]

**Female meiosis:**

- DCO expected: 0.188%
- DCO observed: 0.086%
- COI = .046

**Sturtevant, 1913**

<table>
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<tr>
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Sturtevant, 1913
Genetic Mapping

Fig. 1.

Sturtevant, 1913

Morgan, Sturtevant, Bridges, Muller ~1931
Sex-linked lethal mutations

Correns 1905

2:1 female : male ratio reveals sex-linked lethal
Attached X

Mutagenesis

No males reveals sex-linked lethal
Non disjunction

The white-eyed male, bred to his red-eyed sisters, produced 1,237 red-eyed offspring, (F₁), and 3 white-eyed males. The occurrence of these three white-eyed males (F₁) (due evidently to further sporting) will, in the present communication, be ignored.

Morgan, 1910

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P

X X ♀ × B XY ♂

regular sperm

non-disjunction sperm

F₁

WX

wX/Y

O

regular ova

WX/wX

WX/Y

WX/wX/Y

WX/O

non-disjunction ova

WX/WX

WX/WX/Y

WX/O

---

F₁

O

XY

regular ova

XO

WX/Y

B ♀

non-disjunction ova

XX

+ ♂

×

B ♂

O

×

B ♂
1927 Hermann Muller demonstrates that X-rays are mutagenic
- Irradiated flies and measured mutations in the offspring
- Focused on lethal mutations
  - 88/758 lethal mutations in treated cultures
  - 1/947 lethal mutations arose in control cultures
  - These data were later used to estimate the size of a gene

Chromosomal aberrations were now easier to isolate:
Somatic crossing over: mosaic generation

**Figure 2.** $y \text{sn}^3/\text{+}$. Crossing over between $y$ and $\text{sn}^3$ at a four strand stage. a. Non-crossover chromatids. b. Two crossover and two non-crossover chromatids. c-e. Three different types of chromatid segregation.
Polytene chromosomes

**Figure 1.** *Drosophila melanogaster* chromosomes (from Painter, 1934; used with permission from Oxford University Press)

- Banding patterns used to verify translocations, inversions, deletions, etc.
- What are chromosomes made of and how do they carry heredity information?