Cytogenetics: (after Jackson):

How did they determine that genes existed and were on chromosomes?

On the road to the Cell Theory

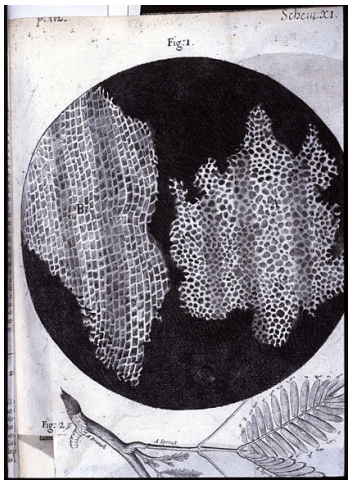


Figure 1. Hooke, Robert, 1635-1703. Micrographia: or some physiological descriptions of minute bodies made by magnifying glasses with observations and inquiries thereupon. London: Printed for John Martyn, 1667.

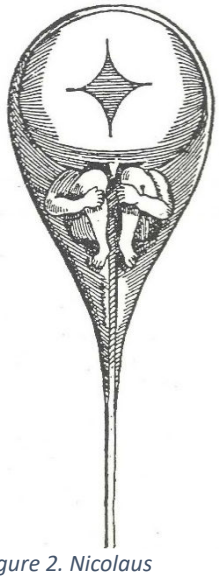
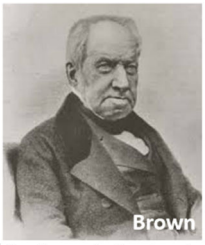
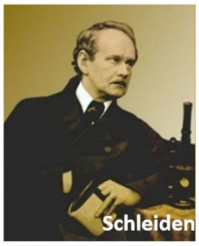


Figure 2. Nicolaus Hartsoeker, 1694, Essai de diotropique

Figure 3. https://en.wikipedia.org/wiki/Caspar_Friedrich_Wolff
https://en.wikipedia.org/wiki/Karl_Ernst_von_Baer
https://en.wikipedia.org/wiki/Marcello_Malpighi

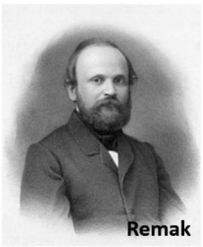


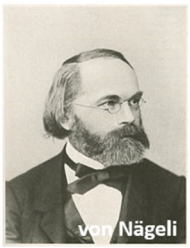


https://www.physik.uni-augsburg.de/theo1/hanggi/History/Robert_Brown_Vortrag.pdf
https://www.sutori.com/item/theodor-schwann-839f
'www.schleiden.uni-jena.de

Where do cells come from?

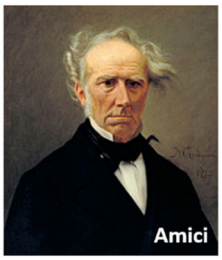
The cell theory

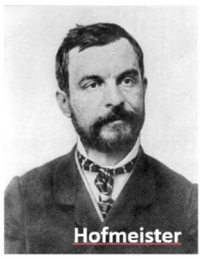




https://en.wikipedia.org/wiki/Robert_Remak
https://en.wikipedia.org/wiki/Carl_N%C3%A4geli
https://en.wikipedia.org/wiki/Rudolf_Virchow

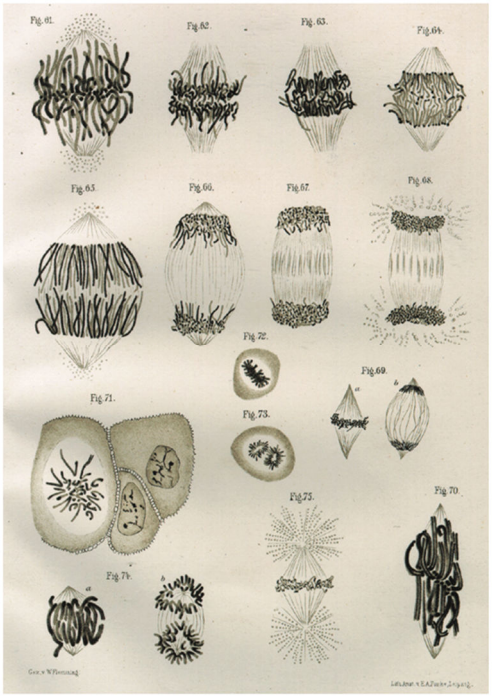
Origin of new individuals

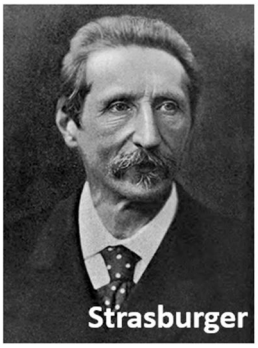




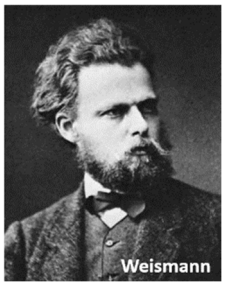
https://prabook.com/web/wilhelm.hofmeister/3723302
https://en.wikipedia.org/wiki/Giovanni_Battista_Amici

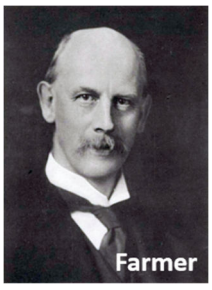
The chromosome theory of heredity





https://www.deutsche-botanische-gesellschaft.de/en/about-us/promoting-young-scientists/eduard-strasburger-prize/vita-eduard-strasburger/
https://www.uni-kiel.de/grosse-forscher/index.php?nid=flemming&lang=e





https://alchetron.com/Oscar-Hertwig
https://en.wikipedia.org/wiki/Carl_Rabl#/media/File:Plate_17_Carl_Rabl,_Photograph_album_of_German_and_Austrian_scientists_(cropped).png
http://www.vliz.be/wetenschatten/beeldbank.php?pic=41628

https://kids.britannica.com/kids/assembly/view/32294

https://www.jstor.org/stable/769107?seq=1#metadata_info_tab_contents

Mitosis:		→		(longitudinal)
?:		→		(transverse)

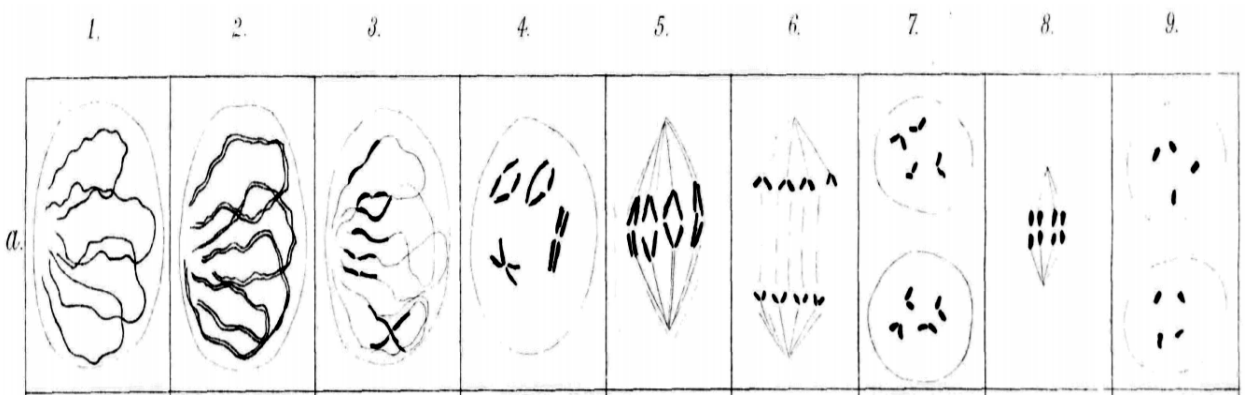
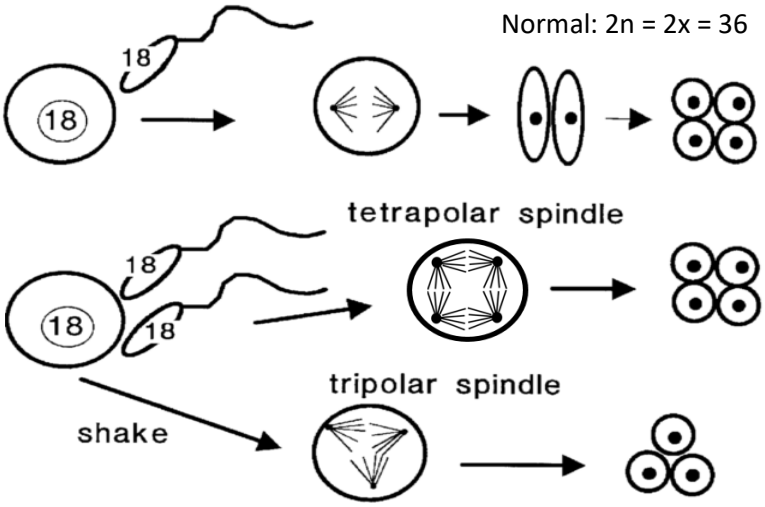


Figure 4 Figure 4 Farmer JB & JES Moore. 1905. On the maiotic phase (reduction divisions) in animals and plants. Quarterly Journal of Microscopical Science 48: 489–557

Discovery that all chromosomes are not alike

Knew ahead of time that:



https://en.wikipedia.org/wiki/Hermann_Fol
https://alchetron.com/Hans-Driesch
https://fineartamerica.com/featured/theodor-boveri-american-philosophical-society.html

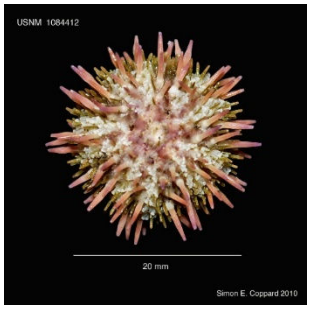


Figure 5
https://eol.org/pages/600396

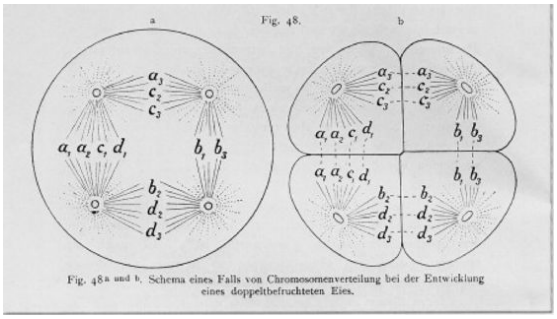
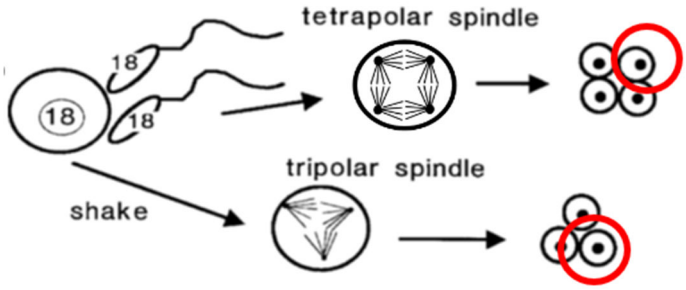


Fig. 48a und b. Schema eines Falls von Chromosomenverteilung bei der Entwicklung eines doppeltbefruchteten Eies.

Discovery that all chromosomes are not alike

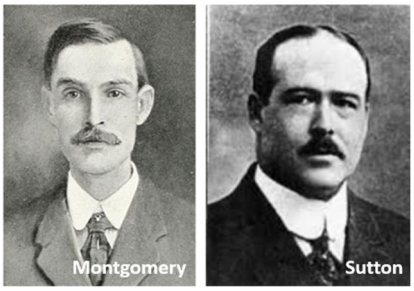
- Theodor Boveri
  - 1500 tetrapolars → 1? normal = 0.1%
  - 719 tripolars → 58 normals = 8%



- 23 tetrapolar → separated into 92 cells → 17 normal = 18%
- 34 tripolar → separated into 102 cells → 44 normal = 43%

Percent of normal gastrulae from one zygote		
	Tripolar (n = 34)	Tetrapolar (n = 23)
4		0.0
3	14.4	4.5
2	22.8	4.5
1	40.0	54.5
0	22.8	36.5

The chromosome theory of heredity



https://en.wikipedia.org/wiki/Thomas_Harrison_Montgomery_Jr.
https://en.wikipedia.org/wiki/Walter_Sutton

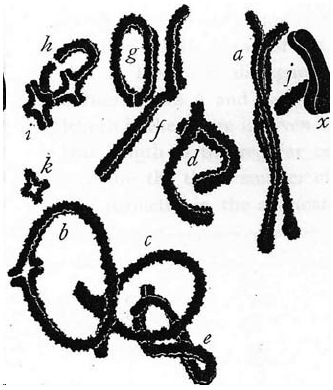
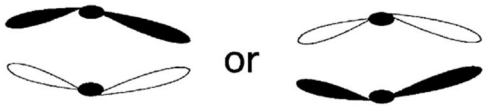
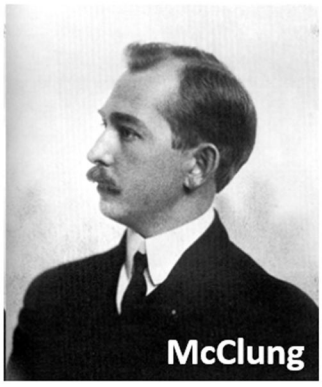


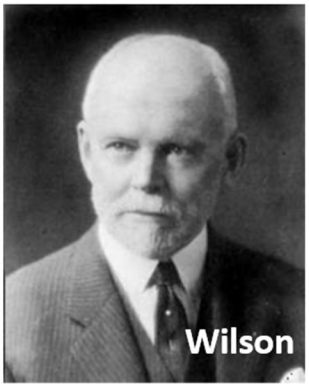
Figure 6 On the morphology of the chromosome group in Brachystola magna, 1902

1	
2	
3	
4	
5	
6	



The sex chromosome





http://www.esp.org/people/
https://www.britannica.com/biography/Edmund-Beecher-Wilson
BRYN MAWR COLLEGE LIBRARY, SPECIAL COLLECTIONS

Independent assortment

1913, 1935 – Estrella Eleanor Carothers

X = the accessory chromosome; c denotes the heteromorphic large/small

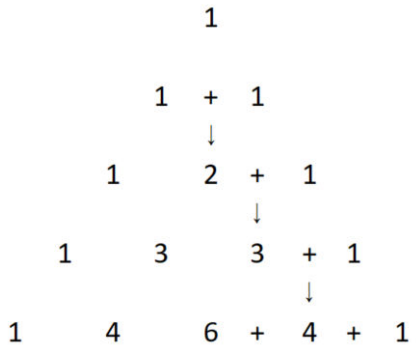
https://en.wikipedia.org/wiki/Eleanor_Carothers

Left: X/large at top; O/small at bottom: $^{154}/_{300}$ = 51.3%
Right X/small at top; O/large at bottom: $^{146}/_{300}$ = 48.7%

Recovery of:	N	Probability	Expected	Observed
A given large chromosome	× 200	½	100	100
2 given large chromosomes	× 200	½ × ½	50	46/47
3 given large chromosomes	× 200	½ × ½ × ½	25	22/21
All large chromosomes	× 200	½ × ½ × ½ × ½	12.5	8

What about recovery of *any* large chromosome?

Calculating probabilities



Recovery of:	Probability	Expected	Observed
Any 1 large chromosome	$4a^3b$	50	48
Any 2 large chromosomes	$6a^2b^2$	75	84
Any 3 large chromosomes	$4ab^3$	50	48
All 4 large chromosomes	b^4	12	8

Non-disjunction

Final proof that genes were on chromosomes

1913 – Calvin Blackman Bridges

- Non-disjunction as proof of the chromosome theory of heredity
- *Genetics* 1:1-53; 107-163

Figure 7. mblhistoryproject.tumblr.com/post/130907349268/people-of-the-lab-calvin-bridges

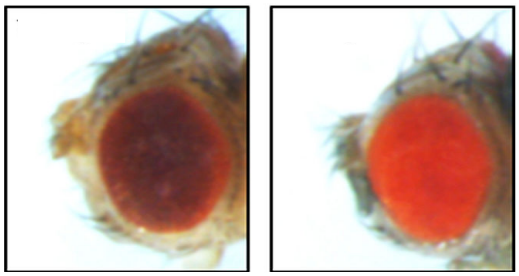


Figure 8. Red eye color in Drosophila. https://bio-protocol.org/e3147

	vermilion ♀ (*v*/*v*)		×	red ♂ (+/Y)		or	red ♀ (+/+)		×	vermilion ♂ (*v*/Y)	
			↓						↓		
F_1	red ♀ (+/*v*)		+	vermilion ♂ (*v*/Y)			red ♀ (+/*v*)		+	red ♂ (+/Y)	
			↓						↓		
F_2	¼ red ♀ (*v*/+)	¼ verm. ♀ (*v*/*v*)	+	¼ red ♂ (+/Y)	¼ verm. ♂ (*v*/Y)		¼ red ♀ (+/+)	¼ red ♀ (+/*v*)	+	¼ red ♂ (+/Y)	¼ verm. ♂ (*v*/Y)

Primary non-disjunction

v/*v* × +/Y

↓

v + + → red ♀

v + Y → vermilion ♂ } normal

$^{1}/_{5000}$ (*v*/*v*) + (+) → *v*/*v*/+ → usually dies
$^{1}/_{5000}$ (*v*/*v*) + (Y) → *v*/*v*/Y → exceptional vermilion ♀
$^{1}/_{1200}$ (--) + (+) → + → exceptional red sterile ♂
$^{1}/_{1200}$ (--) + (Y) → Y → lethal

Secondary non-disjunction

vermilion ♀ (X/X/Y) × red ♂ (X/Y)

↓

♀:	96% red	4% vermilion	} exceptions
♂:	96% vermilion	4% red	

Predictions:

	Eggs - 4 types:			
♂\♀	X^vY	X^v	X^vX^v	Y
X^+	X^vX^+Y red ♀	X^+X^v red ♀	XXX die	X^+Y exc. red ♂
Y	X^vYY verm ♂	X^vY verm ♂	X^vX^vY exc. verm ♀	YY die

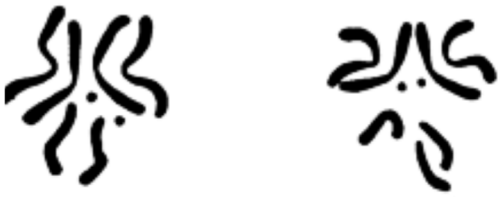


Figure 9. A normal XY (L) and an XXY daughter (R) from an exceptional mother.

1922 – Lilian Vaughn Morgan

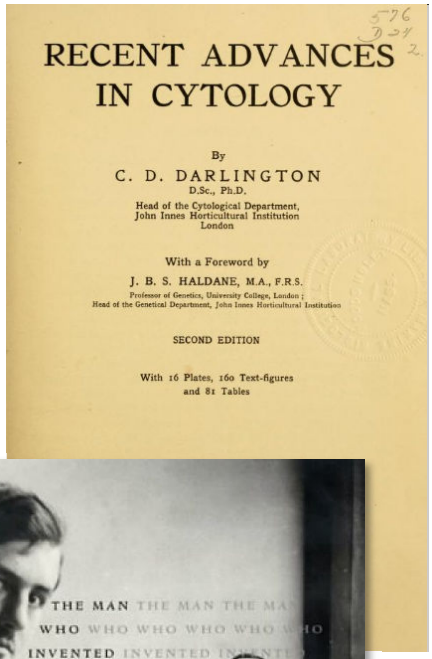
Attached X

Figure 11. A ♀ with an attached X. Such XXXY females survive, while regular XXX condition is lethal.

Figure 10. Wikipedia commons

The Big Picture

1932 – Recent Advances in Cytology
Cyril Dean Darlington


RECENT ADVANCES IN CYTOLOGY

By
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With a Foreword by
J. B. S. HALDANE, M.A., F.R.S.
Professor of Genetics, University College, London; Head of the Genetical Department, John Innes Horticultural Institution

SECOND EDITION

With 16 Plates, 160 Text-figures and 81 Tables