CLASSICAL GENETICS

Multiple Alleles

BOOKLET 2

Topic 2: Multiple Alleles

- **For each trait observed by Mendel, only 2 alleles existed (T & t, for example)**

HOWEVER…

- **Many traits are controlled by multiple alleles**

Multiple alleles = a gene that has more than 2 alleles

Ex. Eye color in Drosophila (fruit flies)

Blood types in humans

Fur color in Rabbits

Eye Color in Drosophila

- 4 alleles control eye color

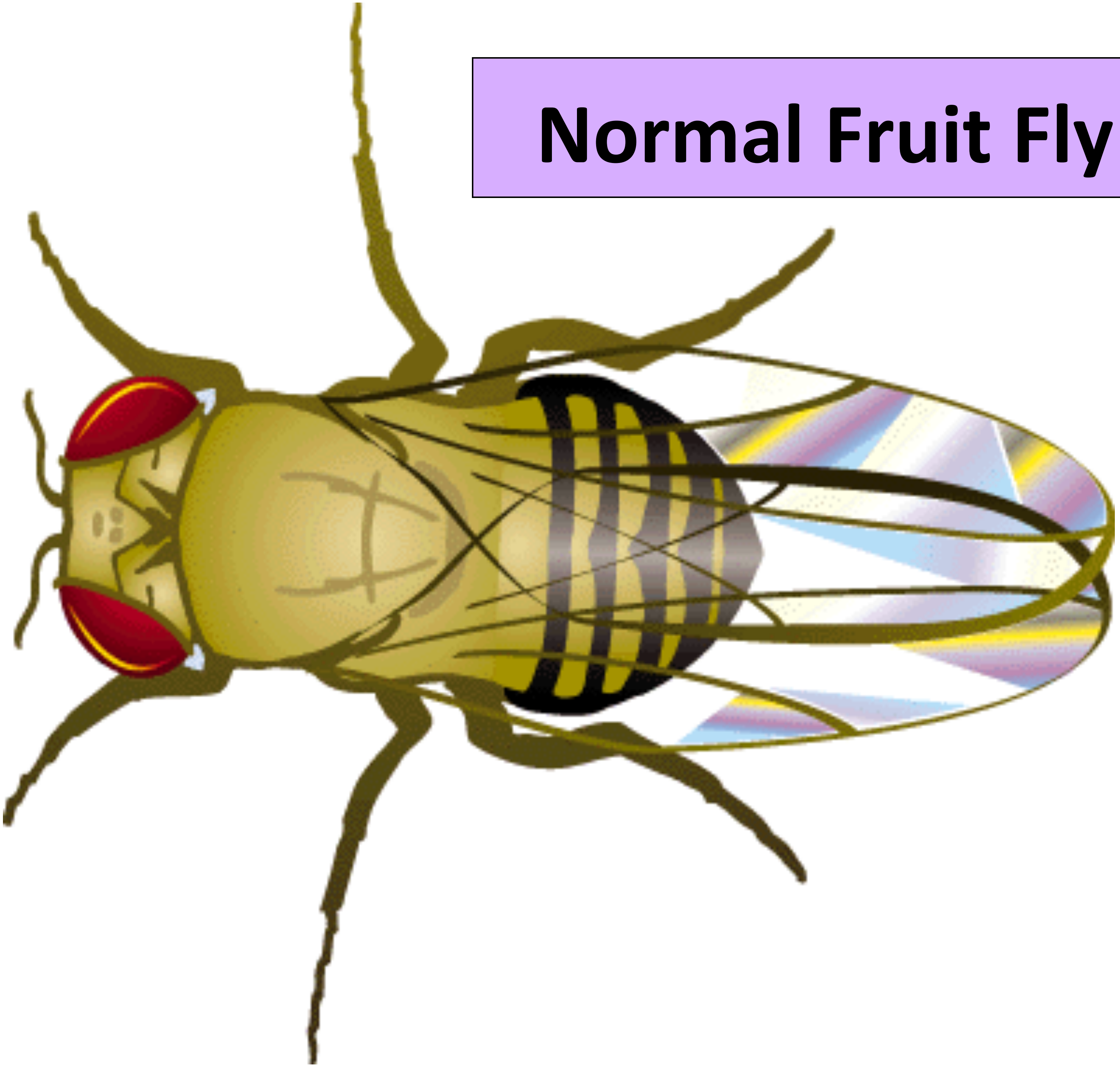
- E^1 = Wild(red) → most commonly seen trait known as WILD
- E^2 = Apricot
- E^3 = Honey
- E^4 = White → least seen trait

There is a dominance order…

$E^1 > E^2 > E^3 > E^4$

Red over Apricot over honey over white

Normal Fruit Fly



Mutant Fruit Flies

Short winged fly

Curly winged fly

Normal fruit fly

Eye Color in Drosophila

Phenotypes	Genotypes
• Wild Type	E^1E^1, E^1E^2, E^1E^3, E^1E^4
• Apricot	E^2E^2, E^2E^3, E^2E^4
• Honey	E^3E^3, E^3E^4
• White	E^4E^4

What do these letters and numbers mean?

E = eye color gene
1 or 2 or 3 or 4 = dominance order
1 is dominant over 2-3-4
2 dominant over 3, 4
3 dominant over 4

(eg) E^1E^3
E^1 is dominant over E^3
so…
The eye colour will be **RED**

Predict the phenotypic outcome if a honey colored heterozygous fly is crossed with a white fly

Parents:
$E^3 E^4$ x $E^4 E^4$

	E^3	E^4
E^4	E^3E^4	E^4E^4
E^4	E^3E^4	E^4E^4

Phenotypes
1 Honey : 1 White

Genotypes
1 E^3E^4 : 1 E^4E^4

What are the possible phenotypes of the parents in a cross which produces the following offspring?

HINT: look for
what is similar
going across
like E^1
and that's one
of the parents
allele

	E^2	E^3
E^1	E^1E^2	E^1E^3
E^3	E^2E^3	E^3E^3

Parent Genotypes

E^1E^3 & E^2E^3

Phenotypes

Wild & Apricot

E^1E^2 & E^1E^3 E^2E^3 & E^3E^3

Another Example of Multiple Alleles:
Rabbit Coat Colour

Phenotype **Possible genotypes**

Gray

CC
Cc^{ch}
Cc^{h}
Cc

Alleles

$C > c^{ch} > c^{h} > c$

Chinchilla

$c^{ch}c^{ch}$

Himalayan

$c^{h}c^{h}$
$c^{h}c$

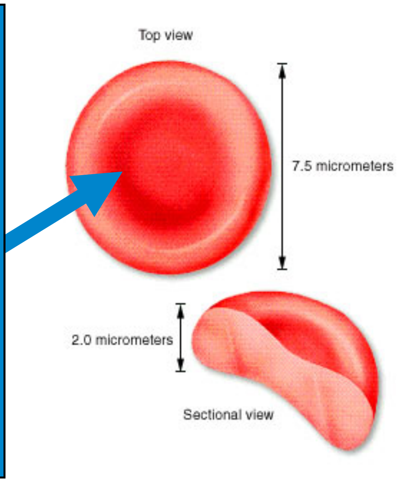
Light gray

$c^{ch}c^{h}$
$c^{ch}c$

Albino

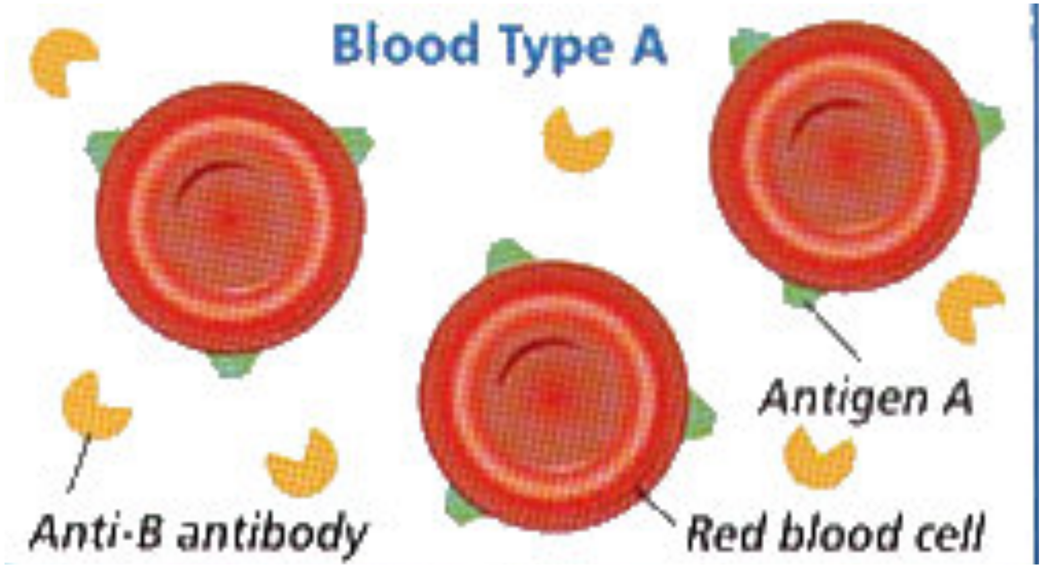
cc

Another Example of Multiple Alleles: Blood Types



Surface marker (antigen) type determines blood type

Blood Type Video



Ex: a person with blood type A, has A antigens on their RBCs

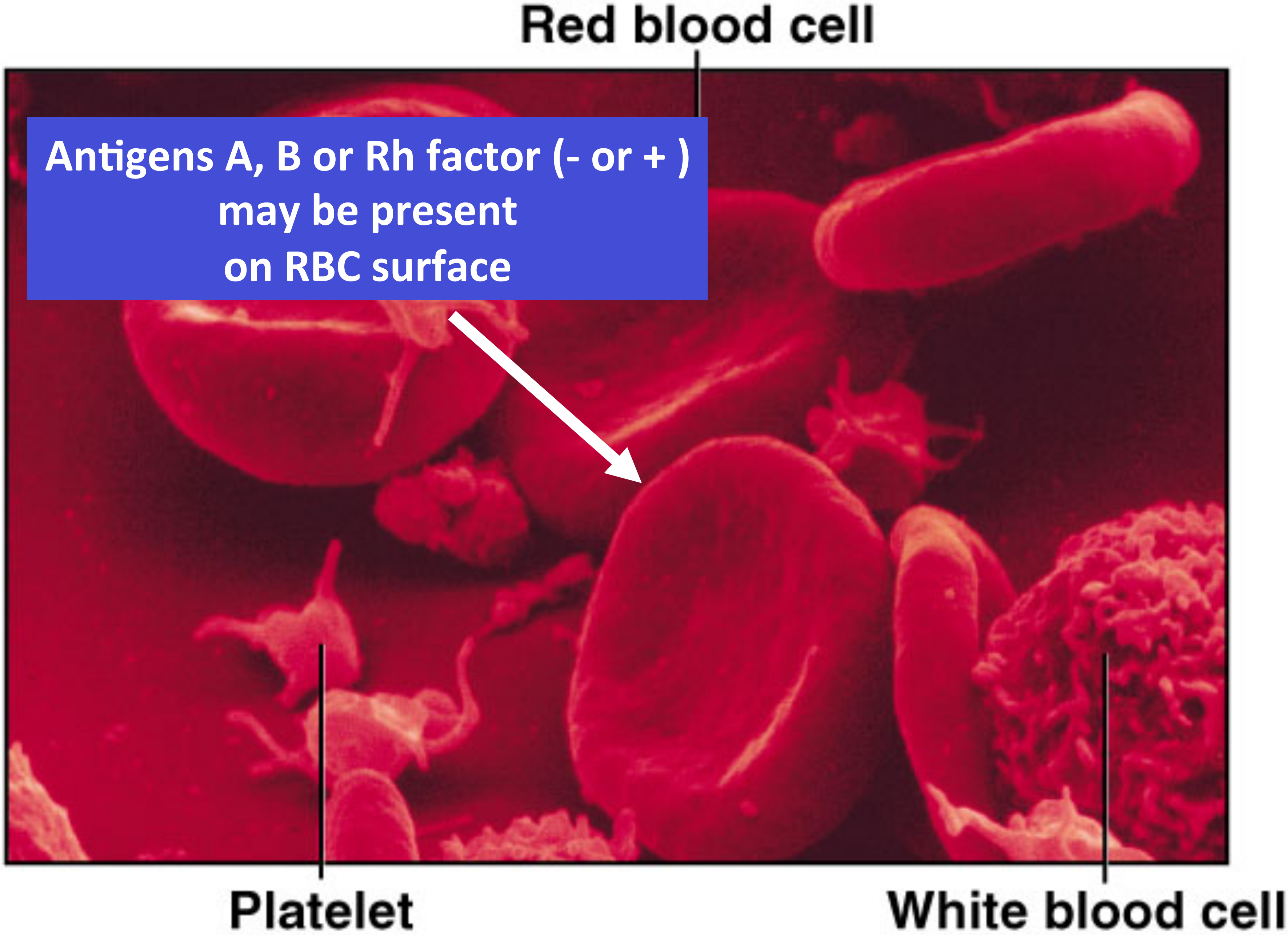
Blood Typing in Humans

- Surface antigen determines **blood type**
- Another example of multiple alleles
- The letter **I** or **i** will represent the blood gene
- Controlled by 3 alleles: I^A, I^B and *i*
- I^A and I^B are said to be codominant

-If a person inherits both of them, then antigen A and antigen B are on the RBC's (and will be blood type AB)

- i is recessive to I^A and I^B

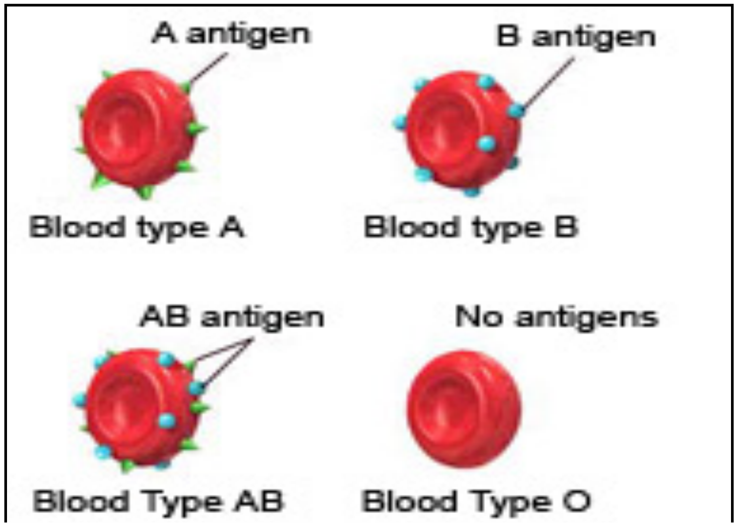
Blood Components



Antigens A, B or Rh factor (- or +)
may be present
on RBC surface

Genotypes and Phenotypes for ABO Blood Types

Genotype	Phenotype (Blood Type)
I^AI^A, I^Ai	A
I^BI^B, I^Bi	B
I^AI^B	AB
ii	O



Predict the phenotypic outcome if a person with blood type AB mates with a person with type O

Remember:
“O” = ii
“AB” = I^A & I^B

	I^A	I^B
i	I^Ai	I^Bi
i	I^Ai	I^Bi

Phenotypes

1 Type A : 1 Type B

Genotypes

1 I^Ai : 1 I^Bi

Blood Typing Problem #1

Mom

Blood Type B

Dad

Unknown

Blood Type

$\cancel{I^BI^B}$

or

$I^B\ i$

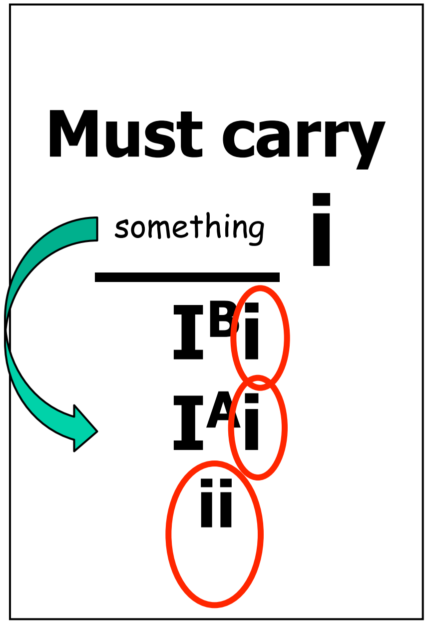
2 possibilities for type "B" but must have an "i" to make babies "ii" (O) type blood

Baby

Blood Type O

ii

Because of "ii", we know baby must get an "i" from mom and "i" from dad



Must carry

something **i**

I^Bi

I^Ai

ii

3 possibilities with an "**i**" that can be passed down

Blood Typing Problem #2

What blood type possibilities can mom, dad and baby be?

Mom
Blood Type A

Dad
Unknown
Blood Type

Baby
Blood Type B

~~I^AI^A~~
or
$I^A i$

2 possibilities for **type A** but must have an "i" passed down otherwise blood type would be "AB" in baby

~~I^BI^B~~ **or** I^Bi

can't be I^BI^B because must be an "i" from mom

(can't be a "B" because otherwise mom would have different blood type with a B)

Must carry
I^B and something

I^BI^B
I^Bi
I^AI^B

3 possibilities so that a I^B can be passed to baby which is makes its type B

Calculating Probability in Genetics

- In genetics, it is often useful to determine the probability (chances) of an event occurring
- Remember: previous events have no effect on future events!
  - Just because you have 3 daughters does not mean that you will have 100% of having a 4th daughter! (The chances of having a daughter is still 50:50!!)

$$\text{Probability (P)} = \frac{\text{number of chances for an event}}{\text{number of possible combinations}}$$

Product Rule:

- **Product Rule:** Used to calculate the probability of two events occurring simultaneously

Product Rule (Probability of two events occurring simultaneously) = **Probability of event 1** x **Probability of event 2**

Calculate the probability of producing a son who is blood type A from the following cross

Must use product rule

	I^A	I^B
i	I^Ai	I^Bi
i	I^Ai	I^Bi

Answer:
0.5 X 0.5 = 0.25
or 25%

Probability of Having *son* = 0.5

(2 out of 4 chances = .5)

X

Probability of having *Type A* = 0.5

(I^Ai & I^ai out of 4 chances= .5)

=.25
25%

Blood Typing and Sex

- **Calculate the probability of producing a daughter who is blood type A from a cross between a Type B mother and a Type A father, given that each of these individuals have a parent with a Type O allele.**

Since parents have "i" allele, both must be carriers for i

Mother must be I^Bi,

Father must be I^Ai

Calculate the probability of producing a daughter who is blood type A from a blood type B mother and blood type A father, given that each of these individuals have a parent with type O blood.

Must use product rule

	I^B	i
I^A	I^AI^B	I^Ai
i	I^Bi	ii

Answer:
0.25 X 0.5 =
0.125
or 12.5%
OR
0.13 (expressed to two digits)

Probability of having *Type A* = 0.25 X **Probability of having a *daughter* = 0.5** = .125

12.5%

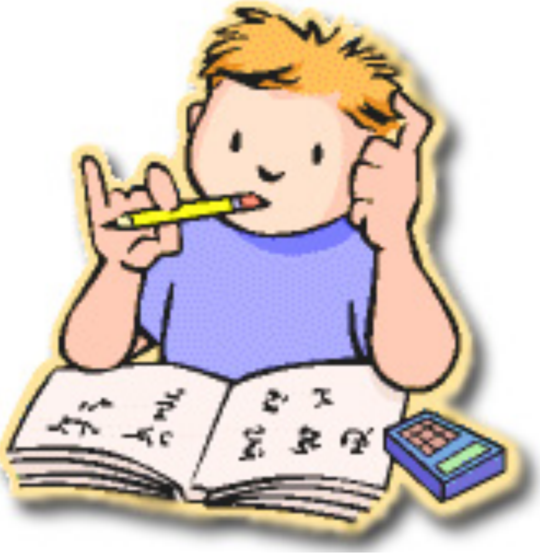
1 chance(I^Ai) **out of** 4 =.25

2 chances **out of** 4 = .5

Genetics Problem Set

http://www.biology.arizona.edu/mendelian_genetics/problem_sets/monohybrid_cross/01q.html

www.biology.arizona



Two more types of inheritance…

INCOMPLETE DOMINANCE

No dominant allele

- Alleles act together to form an intermediate trait

Ex. Snapdragons (flowers)

Red X White = Pink!!

Blending occurs

CODOMINANCE

Both alleles expressed

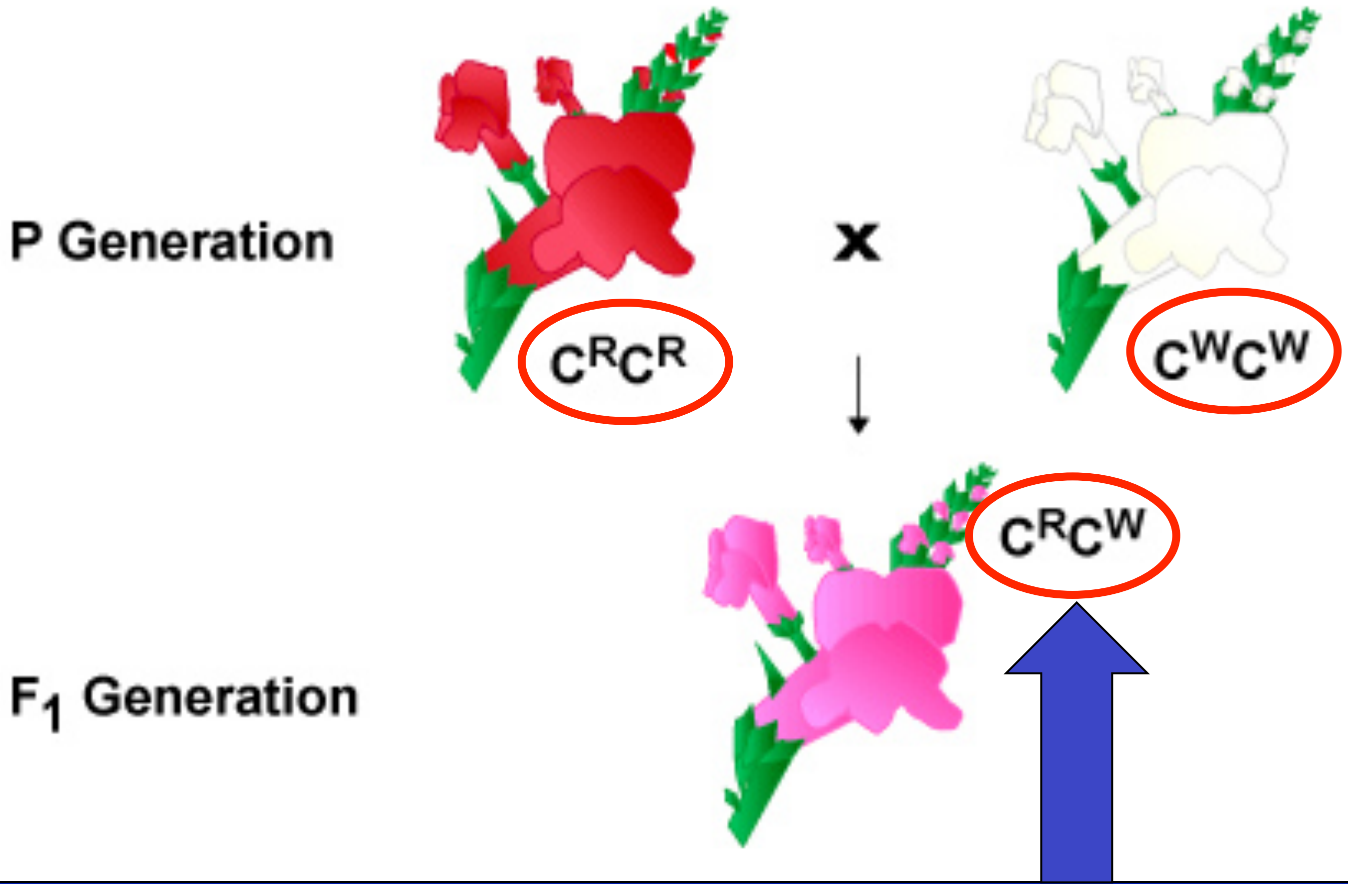
Ex. Cattle

Red X White = Roan

White and red hair present

- Interesting cases which do not show clear dominant or recessive traits

Red X White = Pink

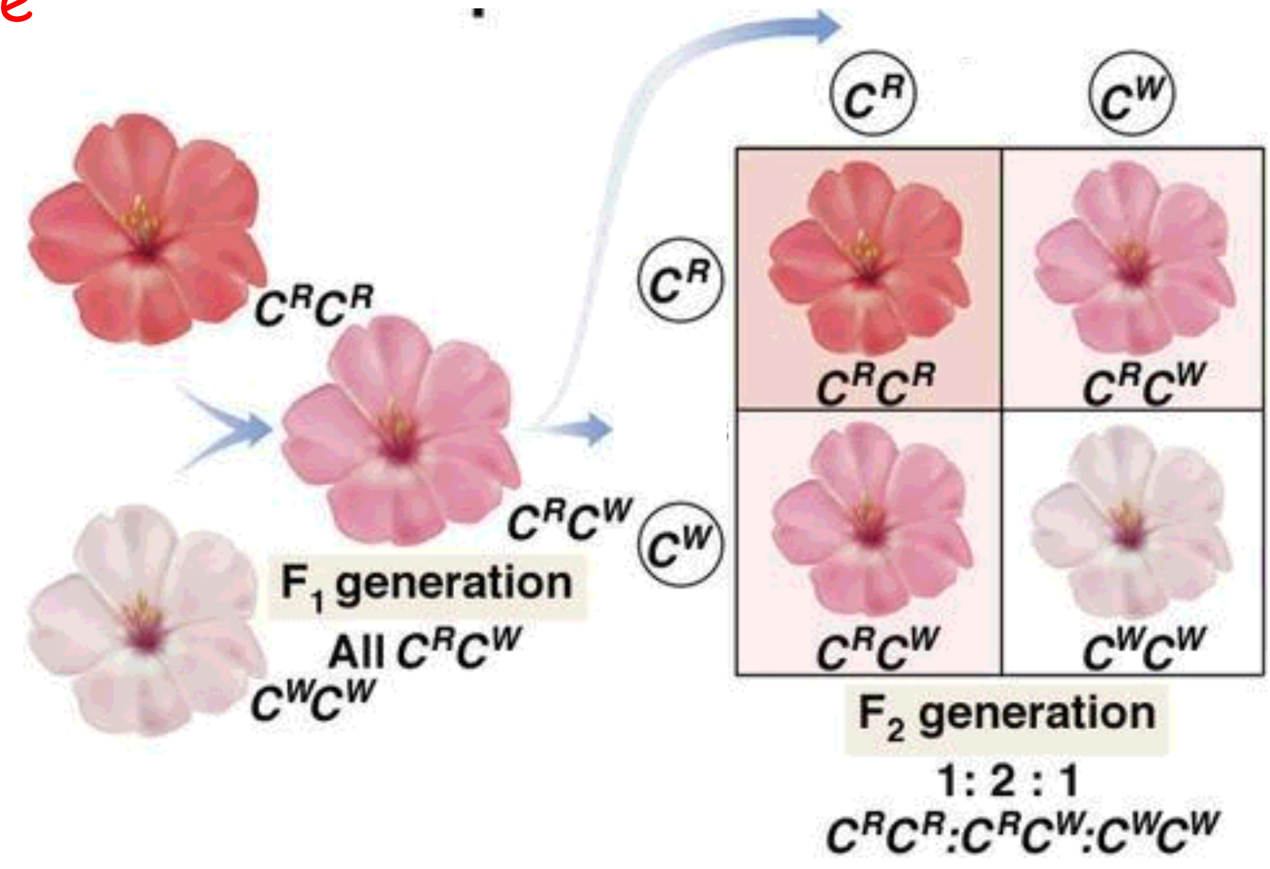


Gene for red (R) is incompletely dominant
to gene for white (W)

Incomplete Dominance: Blending = 3 distinct phenotypes

What if you then mated two pink snapdragons?
What phenotypes would you get?

You get a 1 : 2 : 1 ratio…
1 original white
1 original red
2 pink



Incomplete Dominance

Two alleles mix to form a new color. Blending.


Benjamin Cummings

Codominance

Two alleles are equally dominant. They are combined in the offspring.

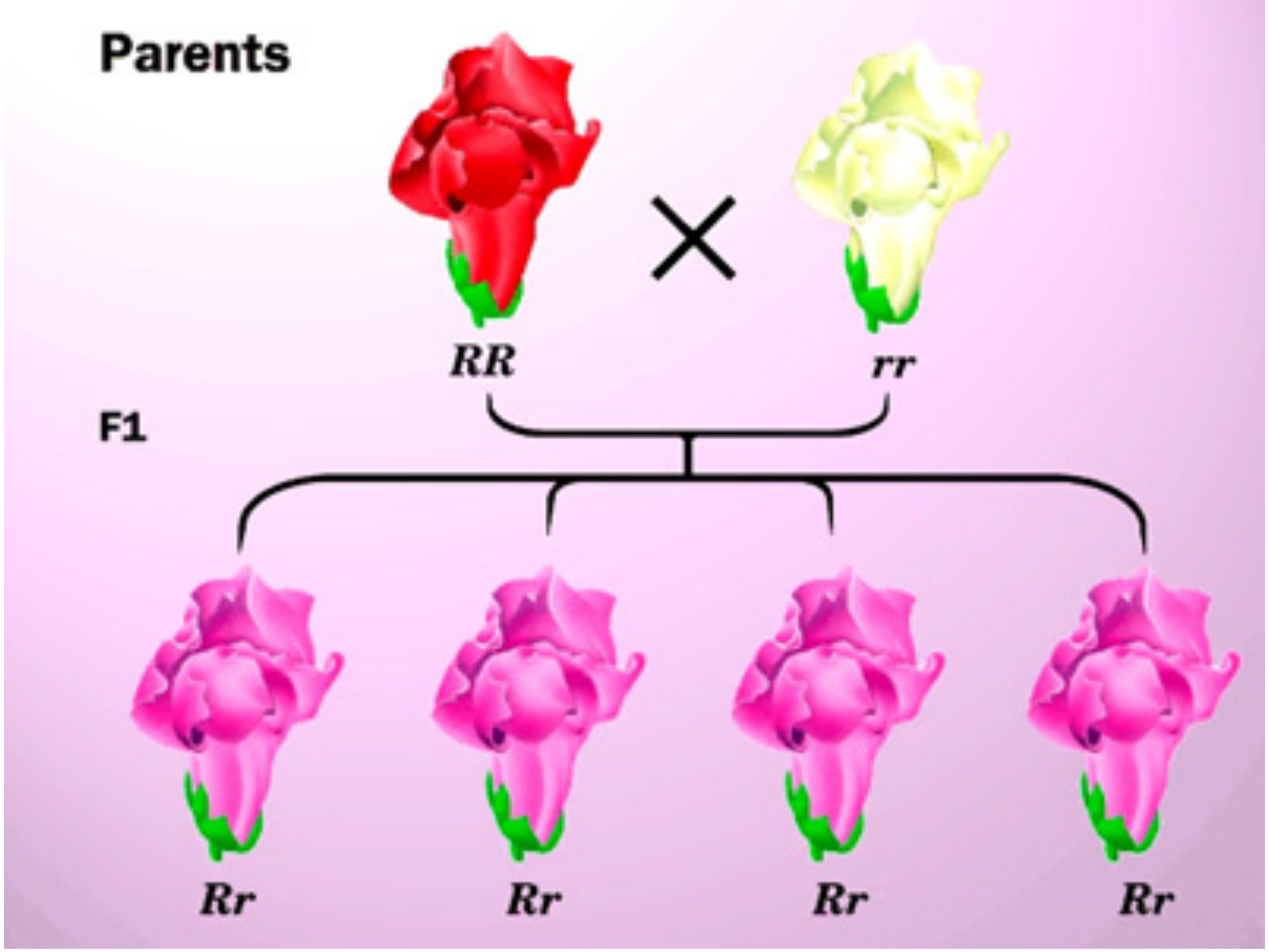
Which one is it?

[✓ **Incomplete Dominance**] **Codominance**

Which one is it?

Incomplete Dominance [✓ Codominance]

Incomplete Dominance Codominance

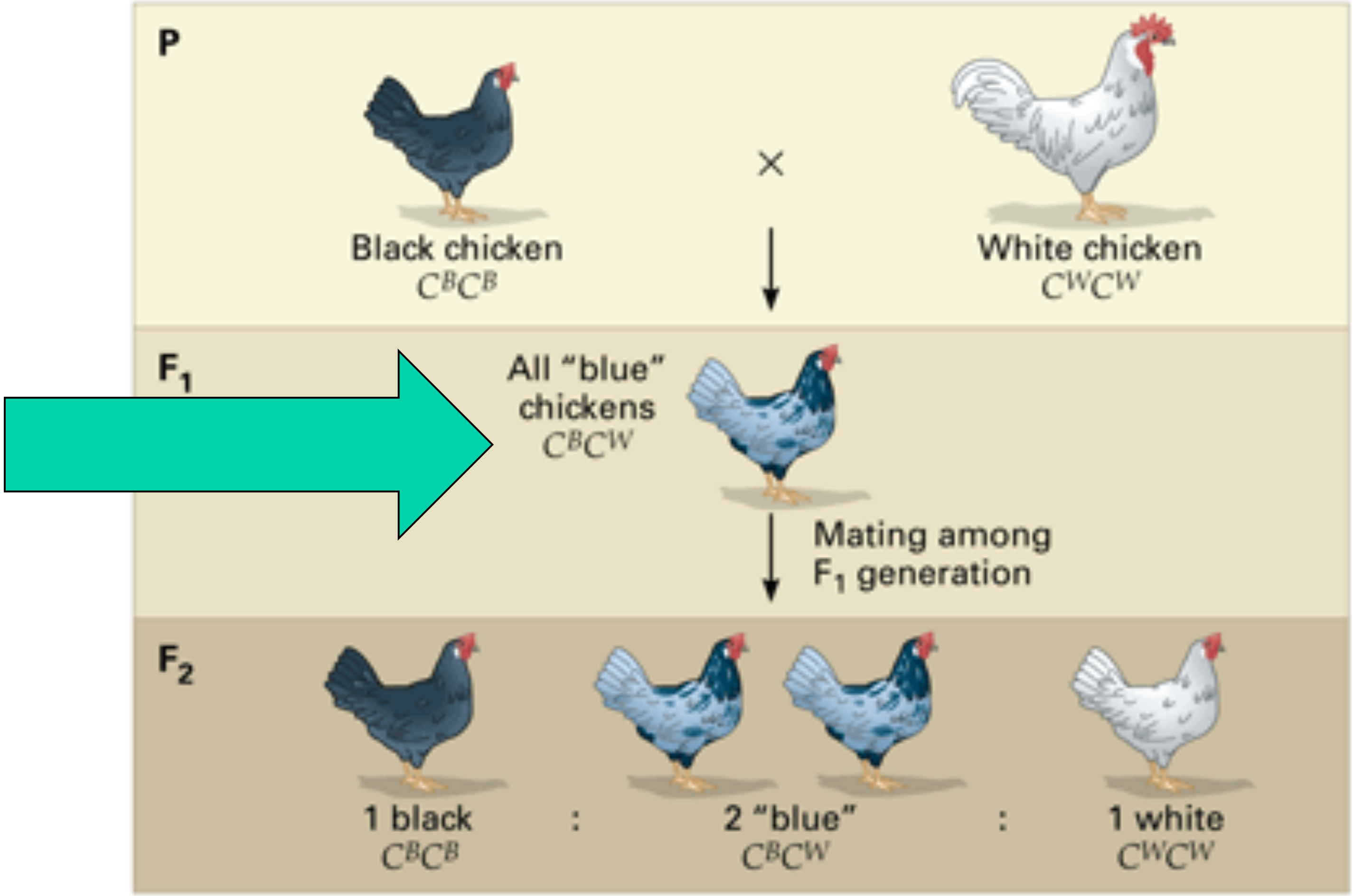


Which one is it?

Incomplete Dominance **[✓ Codominance]**

Which one is it?

Incomplete Dominance **Codominance**



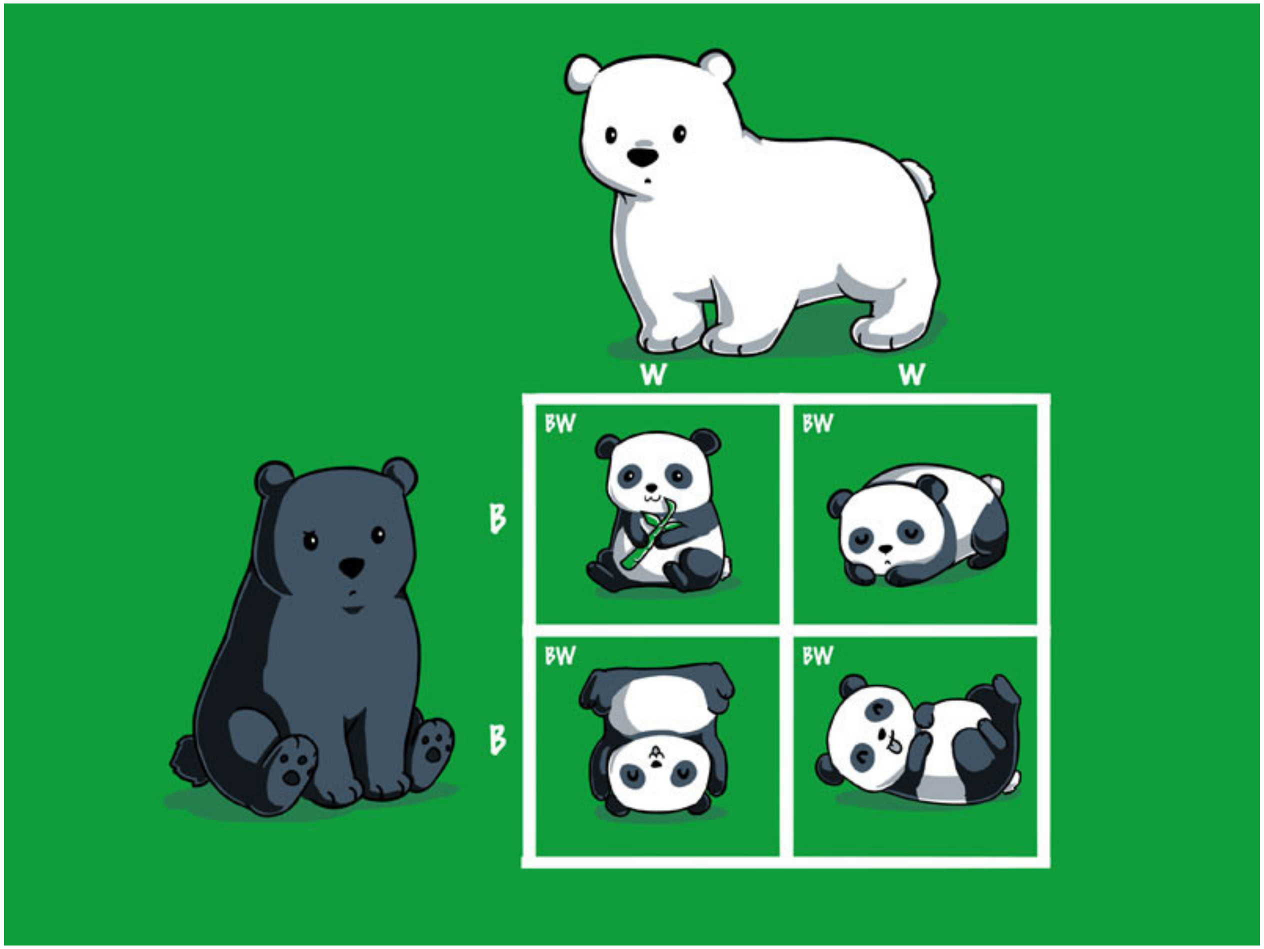
Which one is it?

Incomplete Dominance

Codominance

Which one is it?

Incomplete Dominance [✓ **Codominance**]



Incomplete Dominance Codominance

Which one is it?

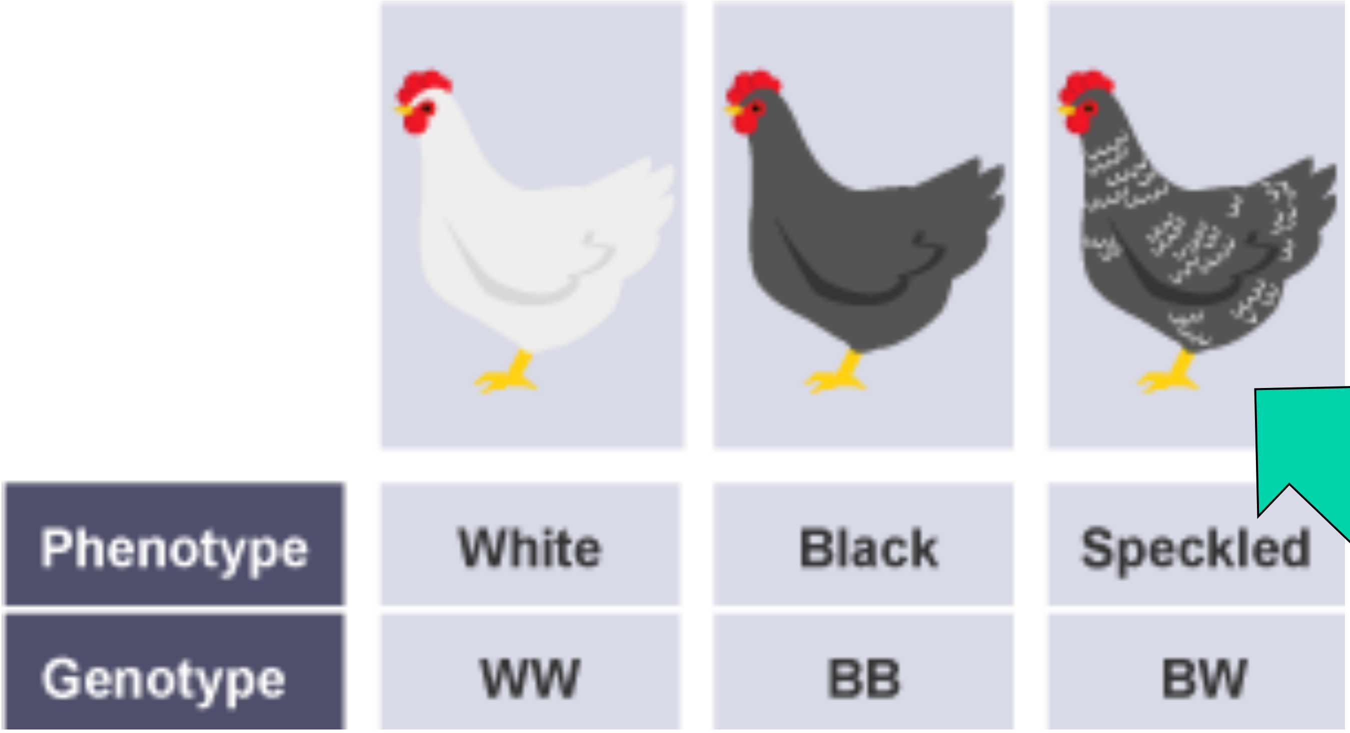
Incomplete Dominance [✓ Codominance]

Which one is it?

Incomplete Dominance [✓ Codominance]

Which one is it?

Incomplete Dominance **Codominance**

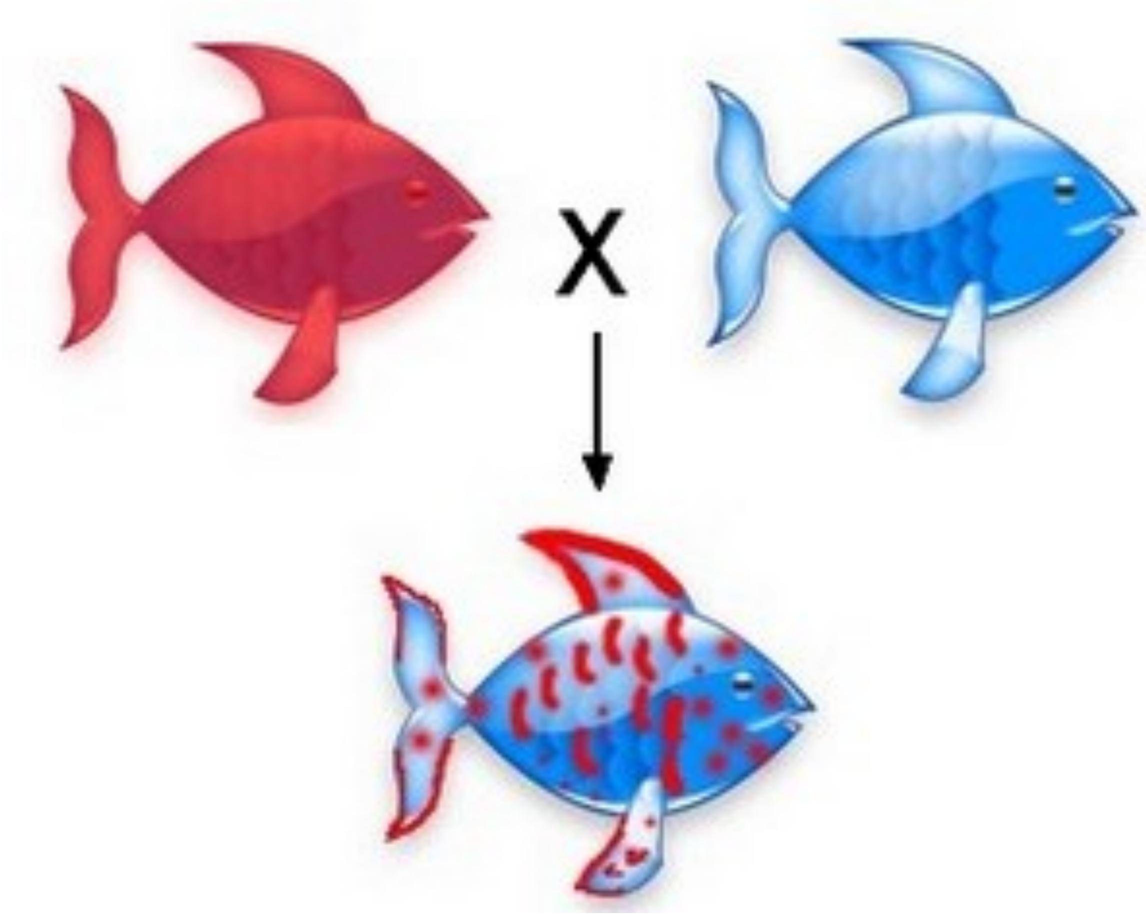


Phenotype	White	Black	Speckled
Genotype	WW	BB	BW

Incomplete Dominance **Codominance**

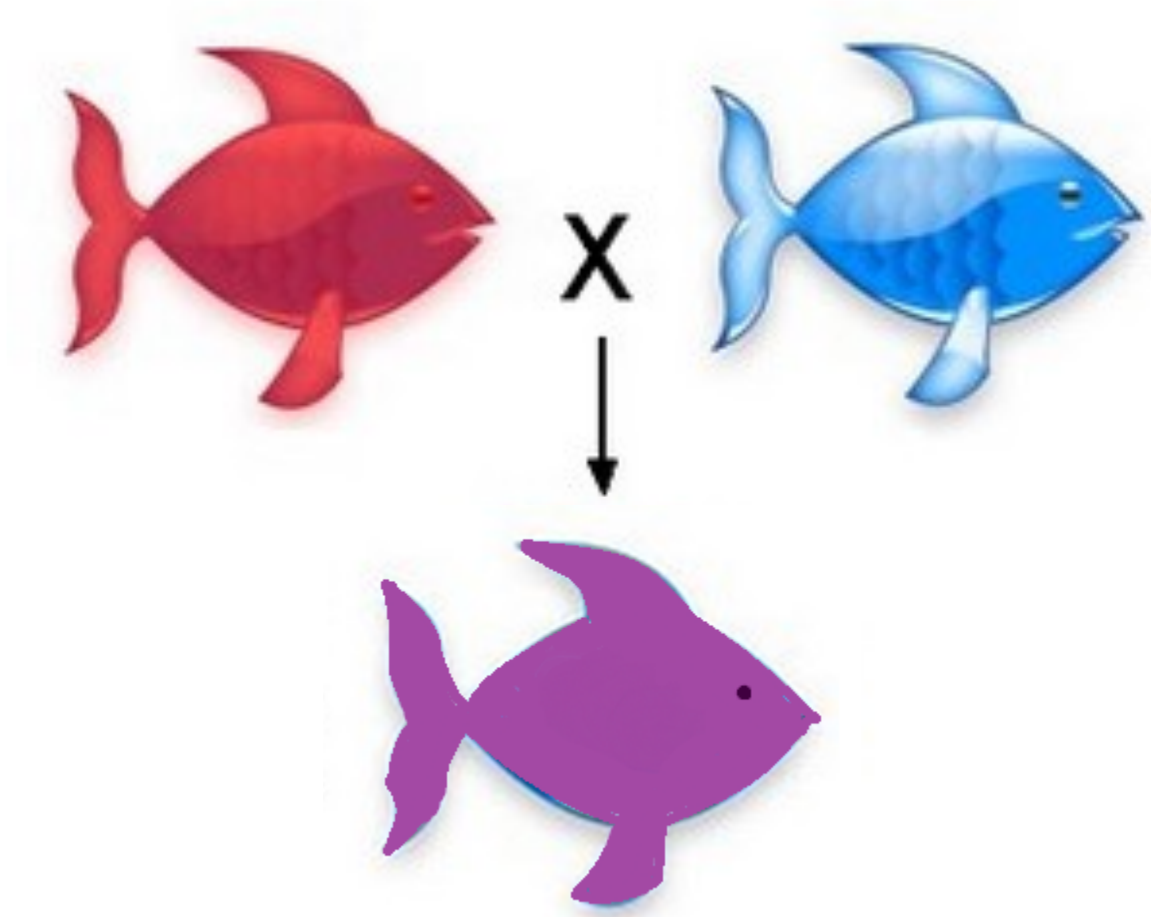
Which one is it?

Incomplete Dominance [✓ Codominance]



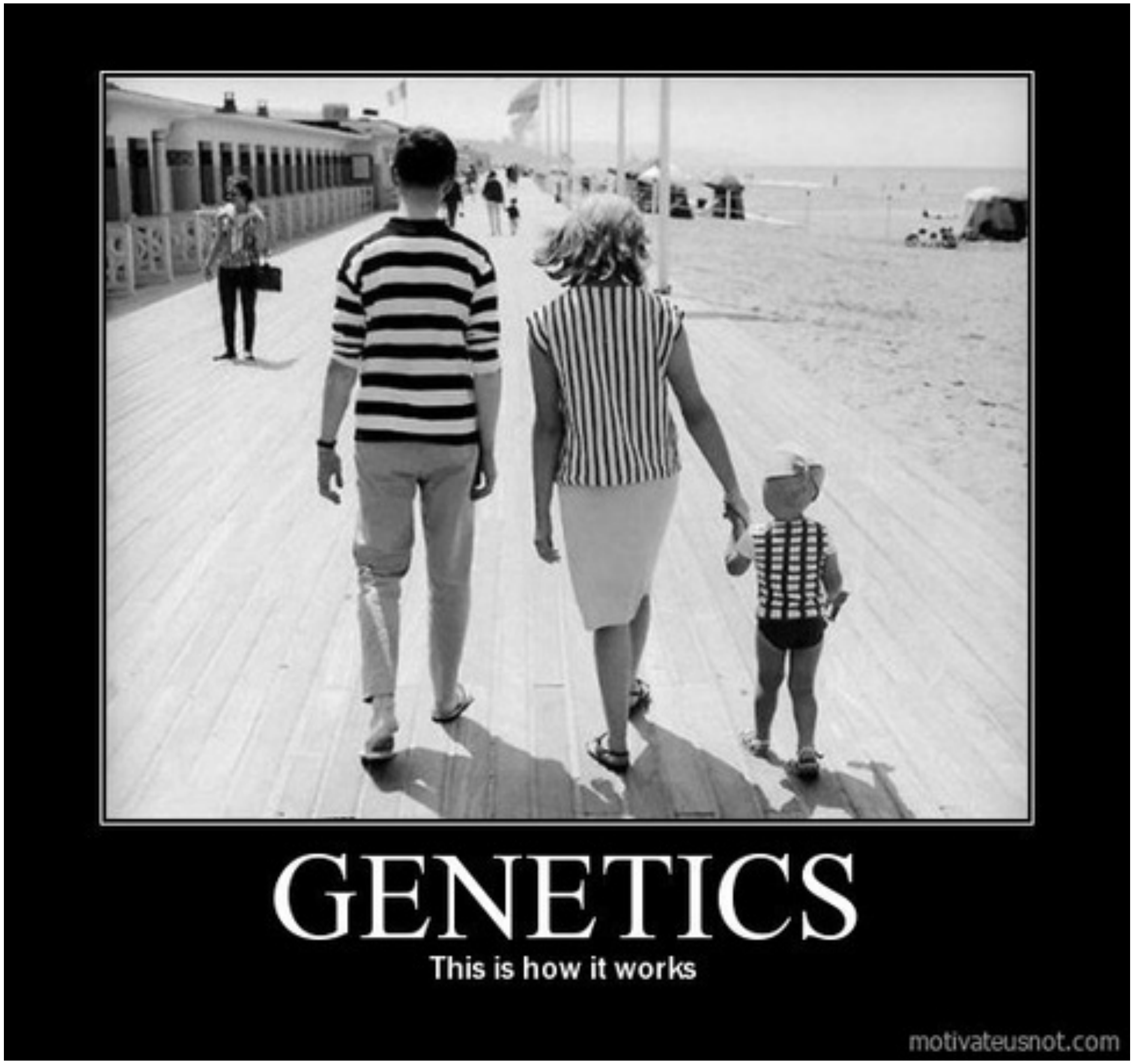
Which one is it?

[✓ Incomplete Dominance] Codominance



Which one is it?

Incomplete Dominance **Codominance**



Predict the phenotypic outcome if a *Red (C^RC^R)* snapdragon is crossed with a *White (C^WC^W)* snapdragon!

	C^R	C^R
C^W	C^RC^W	C^RC^W
C^W	C^RC^W	C^RC^W

Phenotypes

All pink!

Genotypes

All C^RC^W

Predict the phenotypic outcome if a red (C^RC^R) snapdragon is crossed with a pink (C^RC^W) sd!

	C^R	C^R
C^R	C^RC^R	C^RC^R
C^W	C^RC^W	C^RC^W

Phenotypes

1 Red : 1 Pink

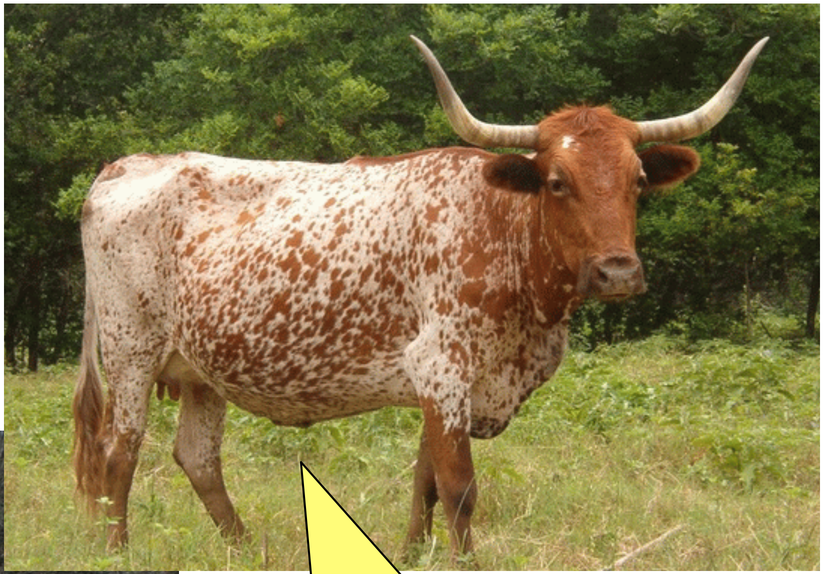
Genotypes

1 C^RC^R : 1 C^RC^W

Codominance

Example: Roan Horse

Horse with white and black hairs evenly mixed



Example: Roan Cattle

Both white and red hairs are visible

Predict the phenotypic and genotypic outcome of the offspring of two red roan horses.

	C^W	C^H
C^W	C^WC^W	C^WC^H
C^H	C^WC^H	C^HC^H

Phenotypes

1 White: 2 Roan:
1 Chestnut

Genotypes

$1\ C^WC^W : 2\ C^WC^H : 1\ C^HC^H$

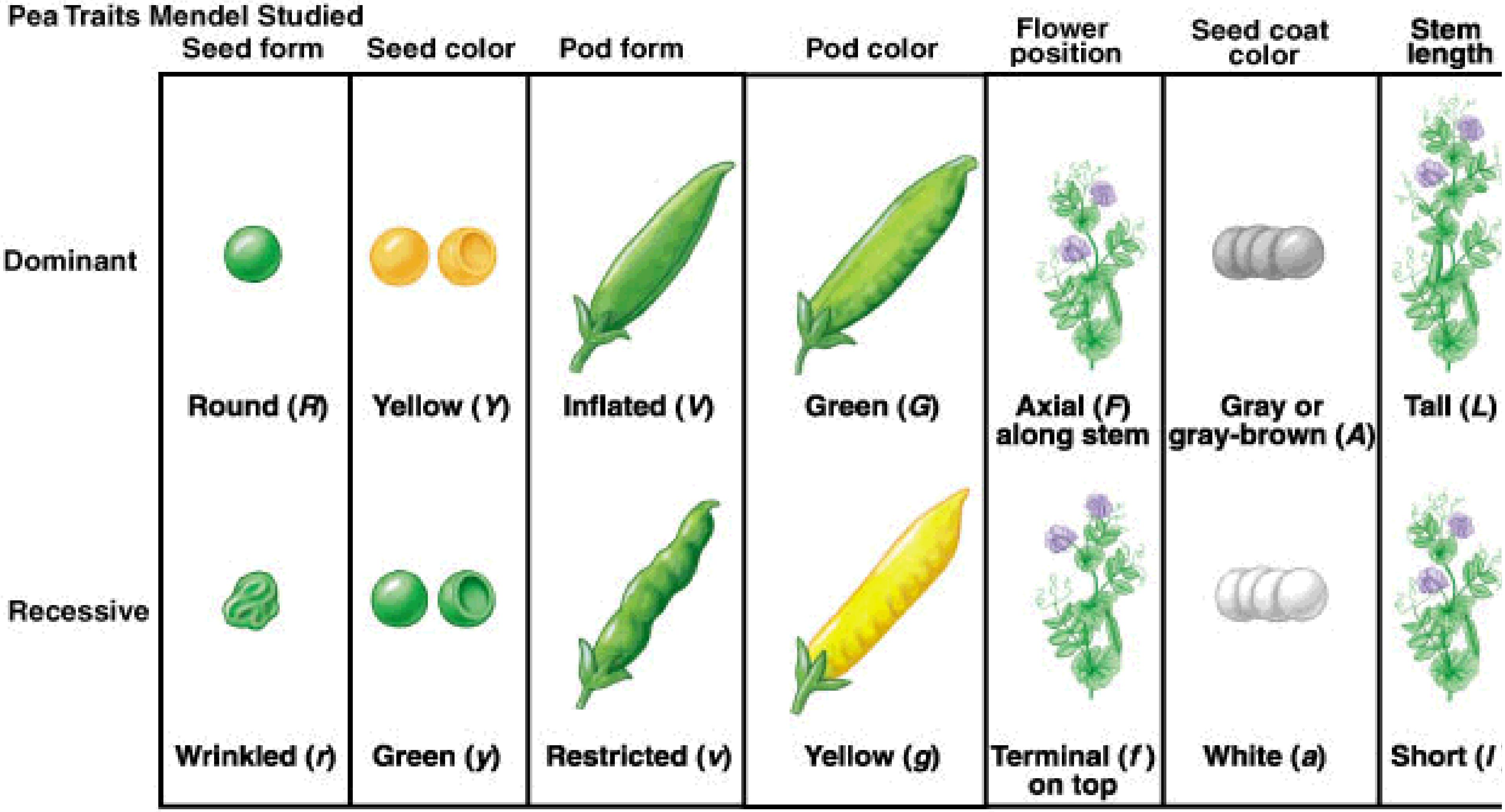
Monohybrid

- *Hybrid* = crossing of two individuals
- *Mono* = looking at **one trait**

Dihybrid

- *Di* = looking at **two traits**
- E.g. what's the chance of a child having both green eyes **AND** brown hair

Dihybrid crosses involve 2 traits



Pea Traits Mendel Studied

	Seed form	Seed color	Pod form	Pod color	Flower position	Seed coat color	Stem length
Dominant	Round (*R*)	Yellow (*Y*)	Inflated (*V*)	Green (*G*)	Axial (*F*) along stem	Gray or gray-brown (*A*)	Tall (*L*)
Recessive	Wrinkled (*r*)	Green (*y*)	Restricted (*v*)	Yellow (*g*)	Terminal (*f*) on top	White (*a*)	Short (*l*

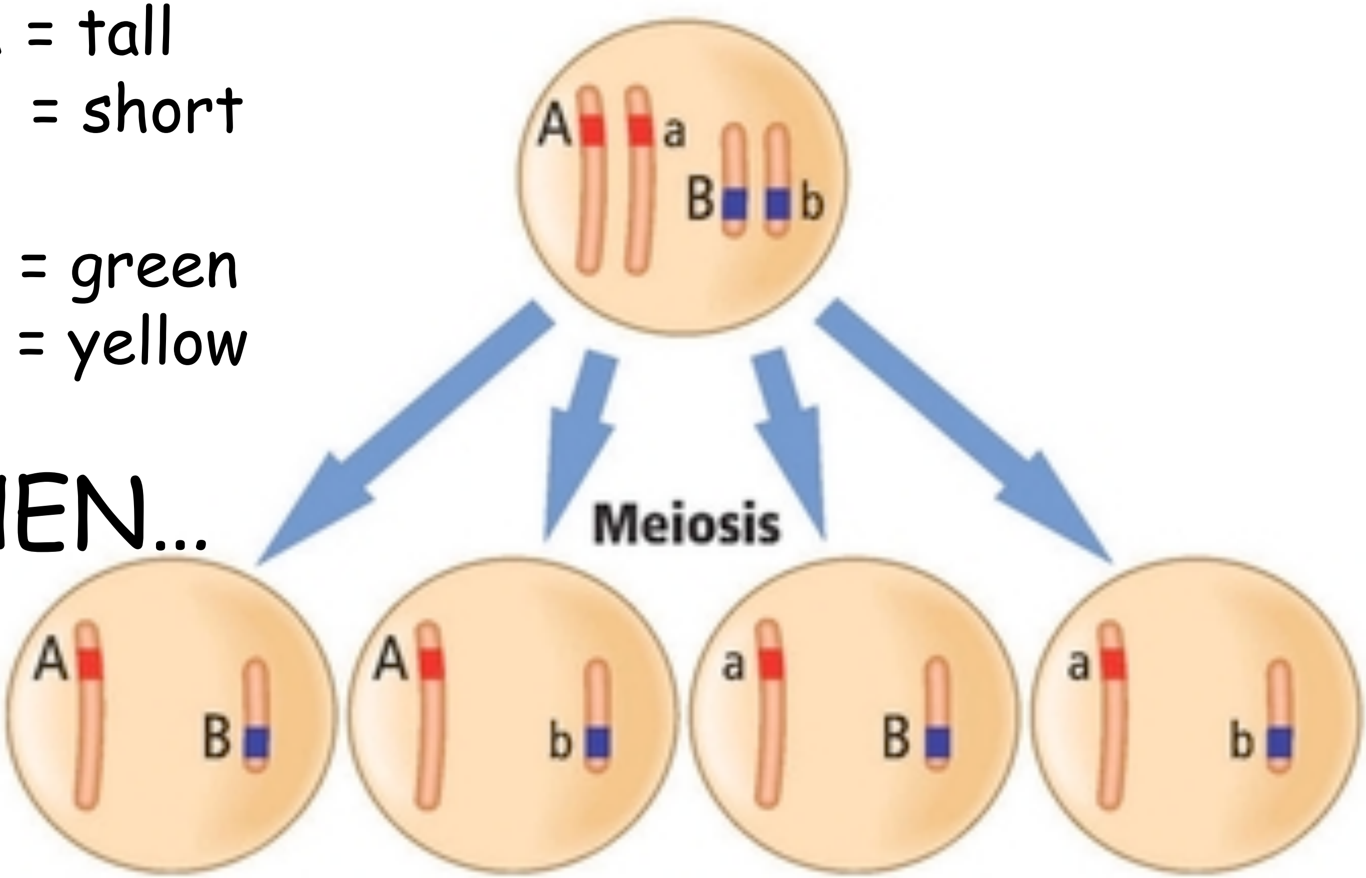
Topic 3 – Interpreting a Dihybrid Cross

IF, for example…

A = tall
a = short

B = green
b = yellow

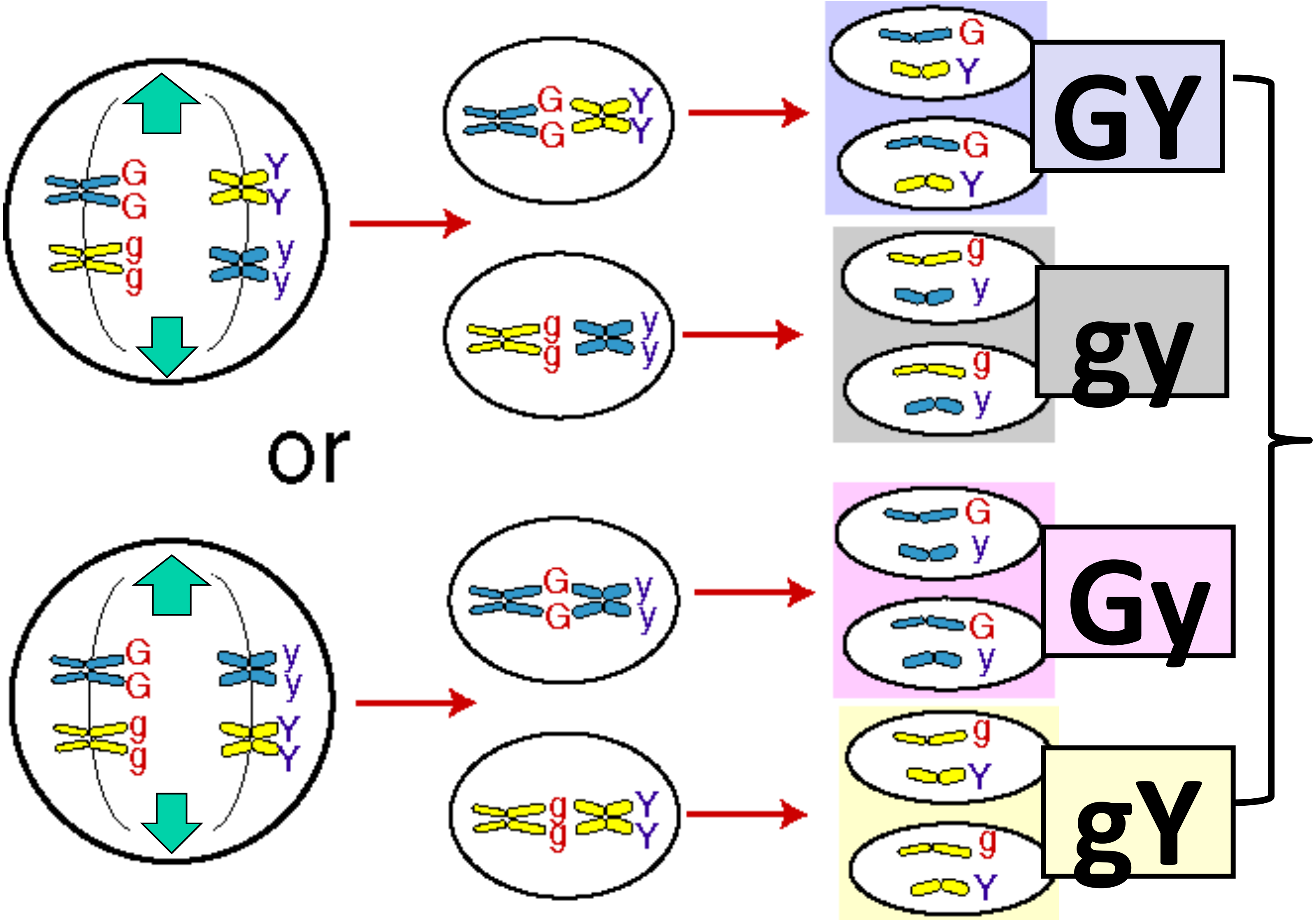
THEN…



Tall green Tall yellow Short green Short yellow

4 different combinations

Remember when we learned about the Law of Independent Assortment?



4 possible gamete combinations

Topic 3 - Dihybrid CROSSES

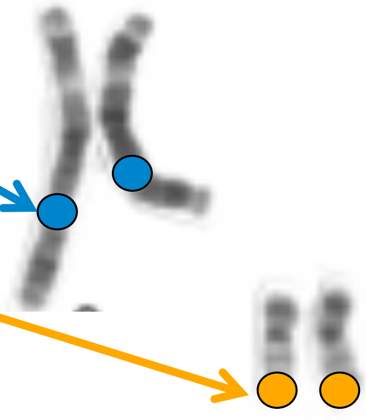
- **INVOLVE 2 TRAITS (genes)**
  - Tall plant: TT
  - Short plant: tt

1 gene on one chromosome

  - Yellow plant: YY
  - Green plant: yy

1 gene on a second chromosome

Two separate chromosomes and two different gene locations:



– Eg. Crossing tall yellow pea plants with short green pea plants → TTYY x ttyy

Topic 3 – Interpreting a Dihybrid Crosses

Your Legend

• **Tall plant:**	**T**	**dominant height**
• **Short plant:**	**t**	**recessive height**
• **Yellow plant:**	**Y**	**dominant colour**
• **Green plant:**	**y**	**recessive colour**

Some possible combination examples:

TtYy = Tall and Yellow plant

ttYY = short and Yellow plant

Ttyy = Tall and green plant

Topic 3 - Dihybrid Crosses

Procedure is same as with monohybrids

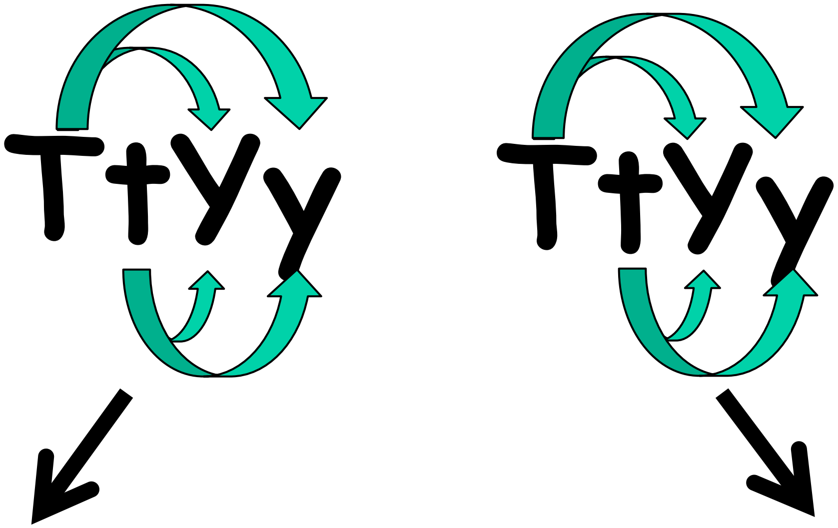
1. **Create legend** (eg) T = tall or Y = yellow
2. **Determine genotypes and gametes**
   (EG) TTYY (see next slide how to create)
3. **Then cross in Punnett square**

OK! Lets do an Example:

What would be the resulting genotypes and phenotypes if we crossed:

TtYy with **TtYy**

work out the gametes

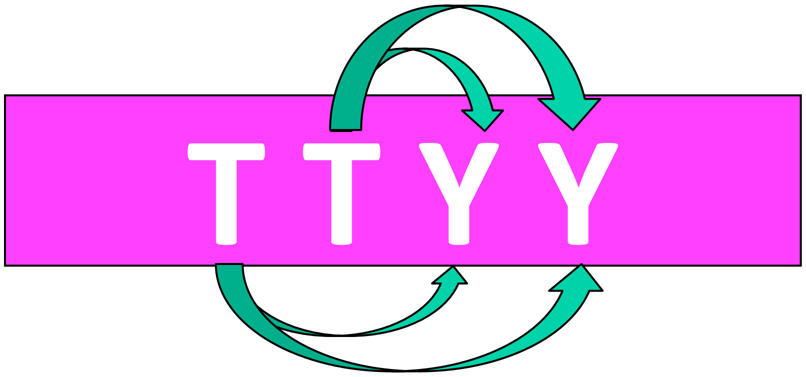


TtYy **TtYy**

TY Ty tY ty

TY Ty tY ty

Working out Gametes in Dihybrid Crosses



TTYY

TY TY

TY TY

TtYY

TY TY

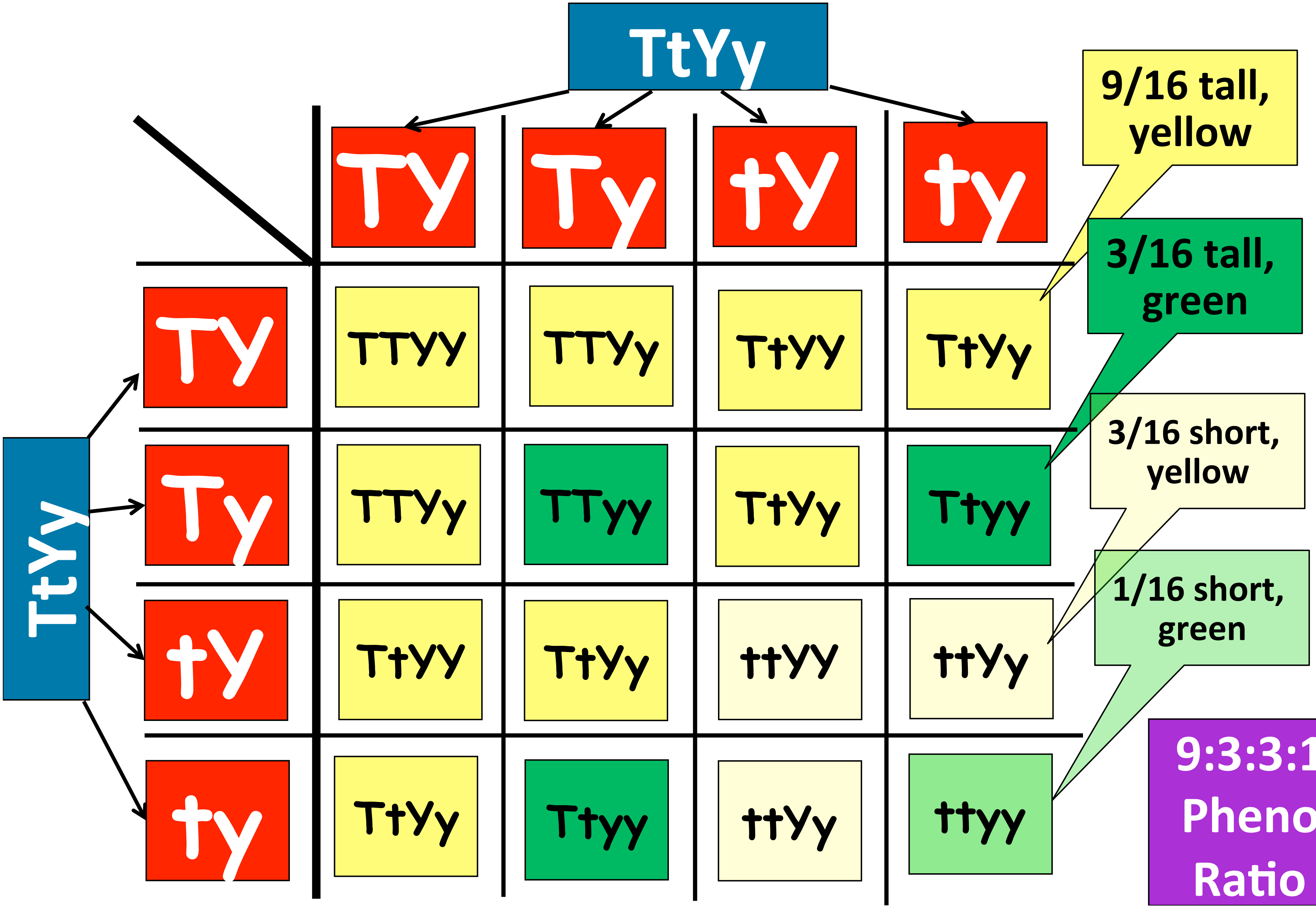
tY tY

TtYy

TY Ty

tY ty

Dihybrid Heteozygous Cross



TtYy

TtYy

	TY	Ty	tY	ty
TY	TTYY	TTYy	TtYY	TtYy
Ty	TTYy	TTyy	TtYy	Ttyy
tY	TtYY	TtYy	ttYY	ttYy
ty	TtYy	Ttyy	ttYy	ttyy

9/16 tall, yellow

3/16 tall, green

3/16 short, yellow

1/16 short, green

9:3:3:1 Pheno Ratio

Example 1: Predict the phenotypic outcome if a heterozygous tall, homozygous yellow pea plant is crossed with TTYY

WARNING!!!
EXTREME SHORTCUT!!!

T = tall
t = short
Y = yellow
y = green

Parental Genotypes
TtYY x TTYY

TY ~~TY~~
tY ~~tY~~

TY ~~TY~~
~~TY~~ ~~TY~~

Get rid of duplicates

	TY	tY
TY	TTYY	TtYY

Phenotypes
All Tall & Yellow

Genotypes
1 TTYY : 1 TtYY

Example 2: A dwarf, red snapdragon is crossed with a homozygous tall white plant.
Determine the phenotype and genotype of the F1's.
(Tall is dominant, red incompletely dominant to white)

Do you know about the EXTREME SHORTCUT?

T = tall
t = dwarf
C^RC^R = Red
C^WC^W = white
C^RC^W = pink

Parental Genotypes
ttC^RC^R x TTC^WC^W

tC^R ~~tC^R~~
~~tC^R~~ ~~tC^R~~

TC^W ~~TC^W~~
~~TC^W~~ ~~TC^W~~

	tC^R
TC^W	TtC^RC^W

Phenotypes: all Tall & Pink
Genotypes: all TtC^RC^W

Example 3: In poultry, a crested head is produced by a dominant allele and a plain head by it’s recessive allele. Black feather is dominant to red. A homozygous red feathered, heterozygous crest headed bird is mated to a heterozygous black, plain headed bird! Find the pheno’s and geno’s of the F 1’s.

Ummm…EXTREME SHORTCUT anyone?

H = crested head
h = plain head
B = Black
b = red

Parental Genotypes
bbHh x Bbhh

bH bh
~~bH~~ ~~bh~~

Bh ~~Bh~~
bh ~~bh~~

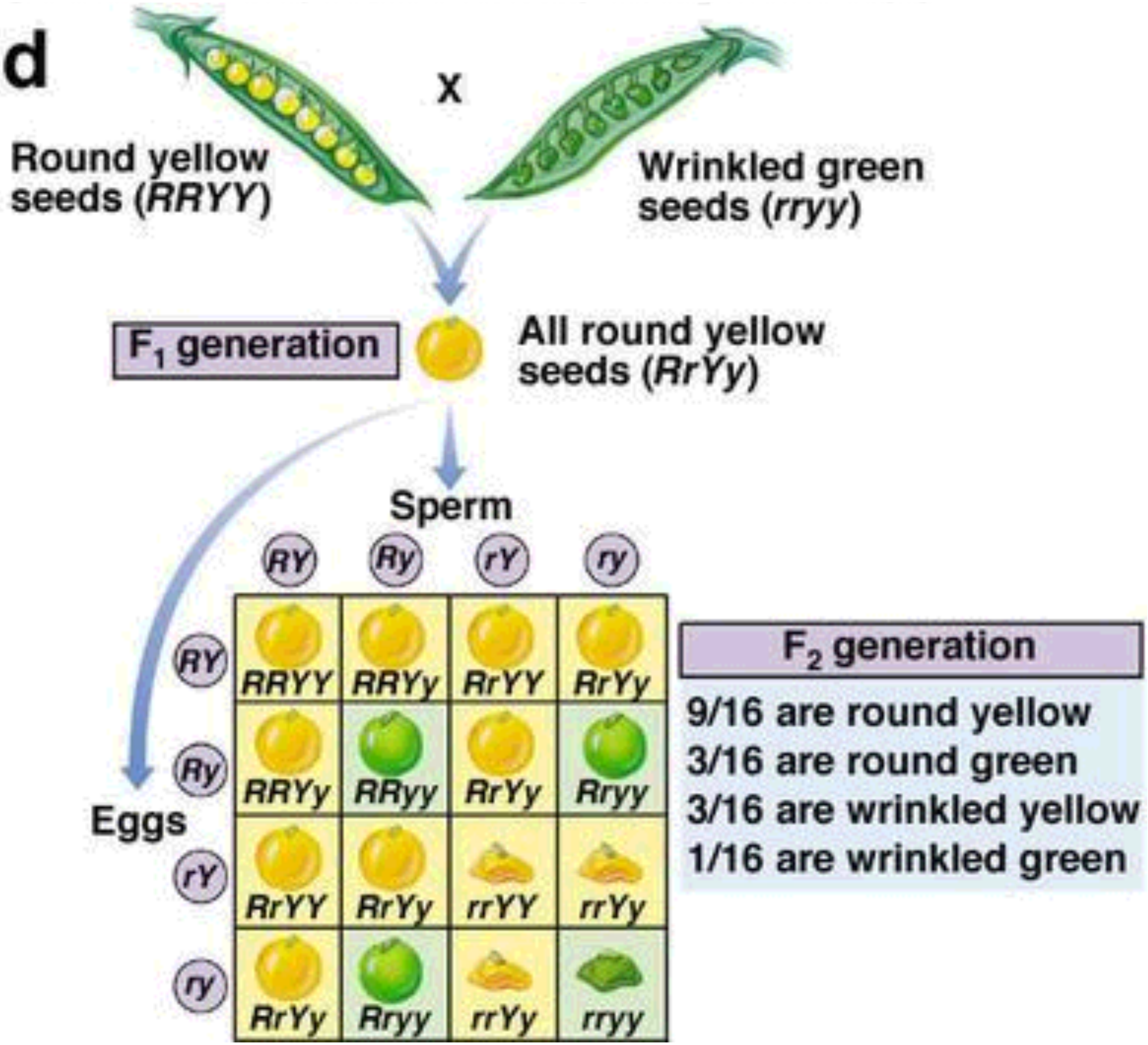
Get rid of duplicates

	bH	bh
Bh	BbHh	Bbhh
bh	bbHh	bbhh

Genotypic Ratio
1:1:1:1

Phenotypic Ratio
1 Black, Crested
1 Black, plain
1 red, Crested
1 red, plain

Dihybrid Cross



Round yellow seeds (*RRYY*)

x

Wrinkled green seeds (*rryy*)

F_1 generation

All round yellow seeds (*RrYy*)

Sperm

Eggs

	RY	*Ry*	*rY*	*ry*
RY	*RRYY*	*RRYy*	*RrYY*	*RrYy*
Ry	*RRYy*	*RRyy*	*RrYy*	*Rryy*
rY	*RrYY*	*RrYy*	*rrYY*	*rrYy*
ry	*RrYy*	*Rryy*	*rrYy*	*rryy*

F_2 generation

9/16 are round yellow
3/16 are round green
3/16 are wrinkled yellow
1/16 are wrinkled green

Summary of Dihybrid Cross

- Most complex Punnett square involves 2 parents heterozygous for both traits
  - eg. RrBb X RrBb
- 4 possible gametes from each parent
- Punnett square is 4 X 4 = 16 combinations
- 9:3:3:1 phenotypic ratio in offspring

Summary con't…

- If parents are RRBb and RrBB
- Only 2 possible gametes from each parent

(b/c of homozygous "RR" and "BB")

(RB or Rb) and (RB or rB) – USE EXTREME SHORTCUT

- Punnett square becomes 2 X 2 instead of 4 X 4!

	RB	Rb
RB	RRBB	RRBb
rB	RrBB	RrBb

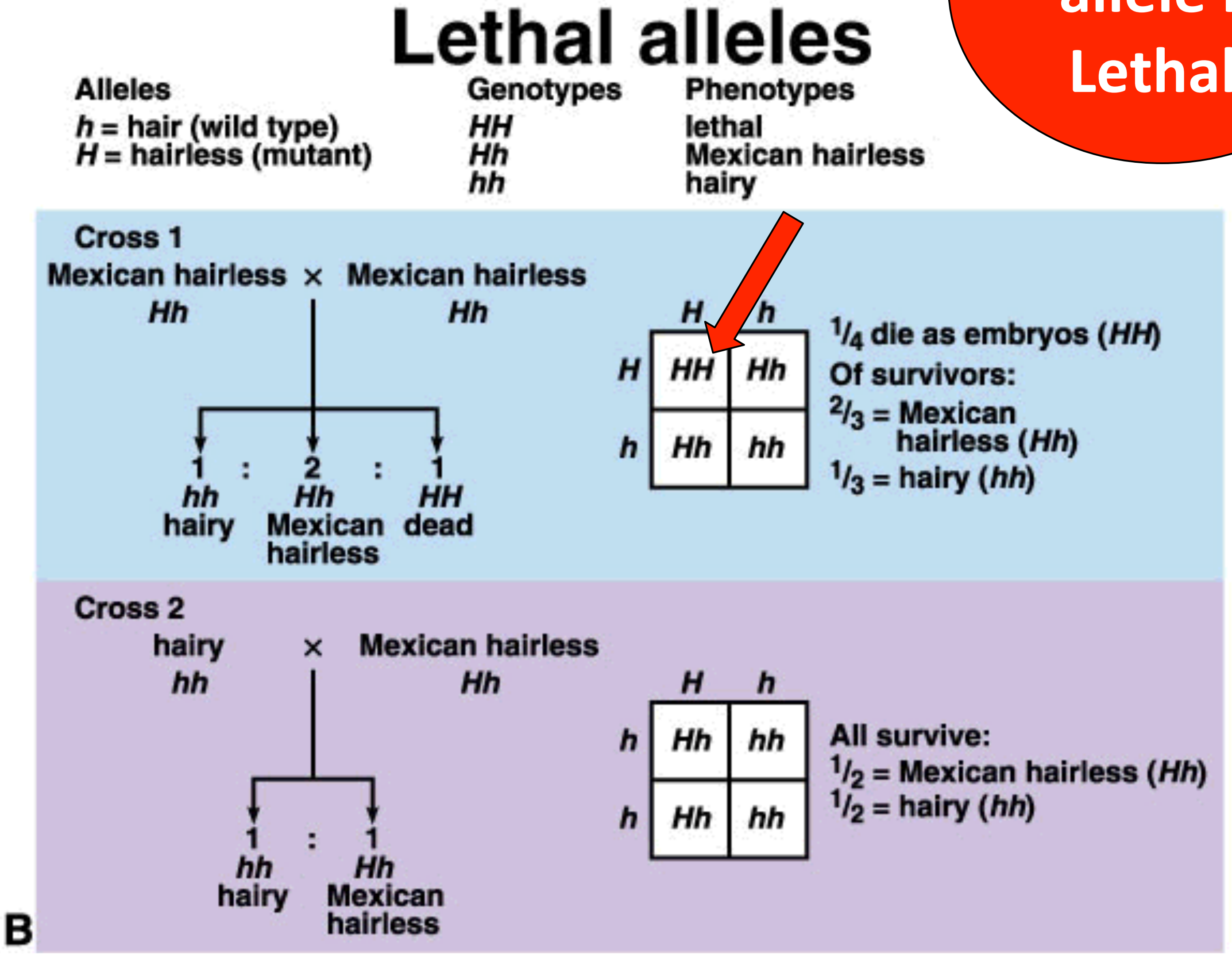
Bozeman video PUNNETT SQUARES

http://www.youtube.com/watch?v=ya7h-Y-9l8c&safety_mode=true

Lethal Alleles

Lethal Allele: allelles capable of causing the death of an organism, usually during the development of the embryo

Dominant allele is Lethal!



Lethal alleles

Alleles	Genotypes	Phenotypes
h = hair (wild type)	HH	lethal
H = hairless (mutant)	Hh	Mexican hairless
	hh	hairy

Cross 1

Mexican hairless × Mexican hairless

Hh × Hh

1 : 2 : 1

hh hairy : Hh Mexican hairless : HH dead

	H	h
H	HH	Hh
h	Hh	hh

$^1/_4$ die as embryos (HH)

Of survivors:

$^2/_3$ = Mexican hairless (Hh)

$^1/_3$ = hairy (hh)

Cross 2

hairy × Mexican hairless

hh × Hh

1 : 1

hh hairy : Hh Mexican hairless

	H	h
h	Hh	hh
h	Hh	hh

All survive:

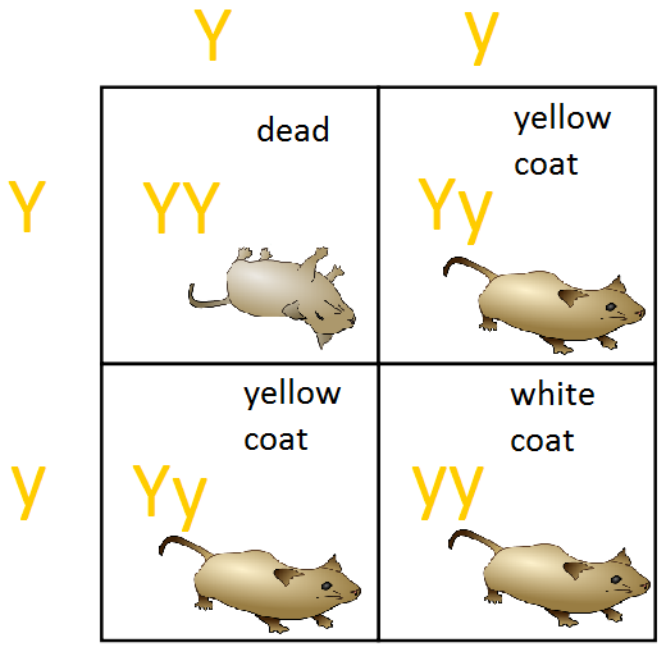
$^1/_2$ = Mexican hairless (Hh)

$^1/_2$ = hairy (hh)

Mexican hairless dog!!

Hh

Lethal genes were first discovered by Lucien Cuénot while studying the inheritance of coat colour gene in mice. He expected a phenotype ratio from a heterozygote cross of 3 yellow:1 white, but the observed ratio was 2:1. By performing test crosses, he determined that all the yellow mice were heterozygotes and that the yellow colour coat was the dominant phenotypic trait. However, no homozygous yellow mice were obtained. In 1910, William Ernest Castle and C. C. Little reaffirmed Cuénot's discovery of a lethal gene by proving that a quarter of the offspring from crosses between heterozygotes died during embryonic development, due to failure to implant in the uterine lining. The quarter that died were the homozygous yellow mice that Cuénot did not see in his tests.[1]



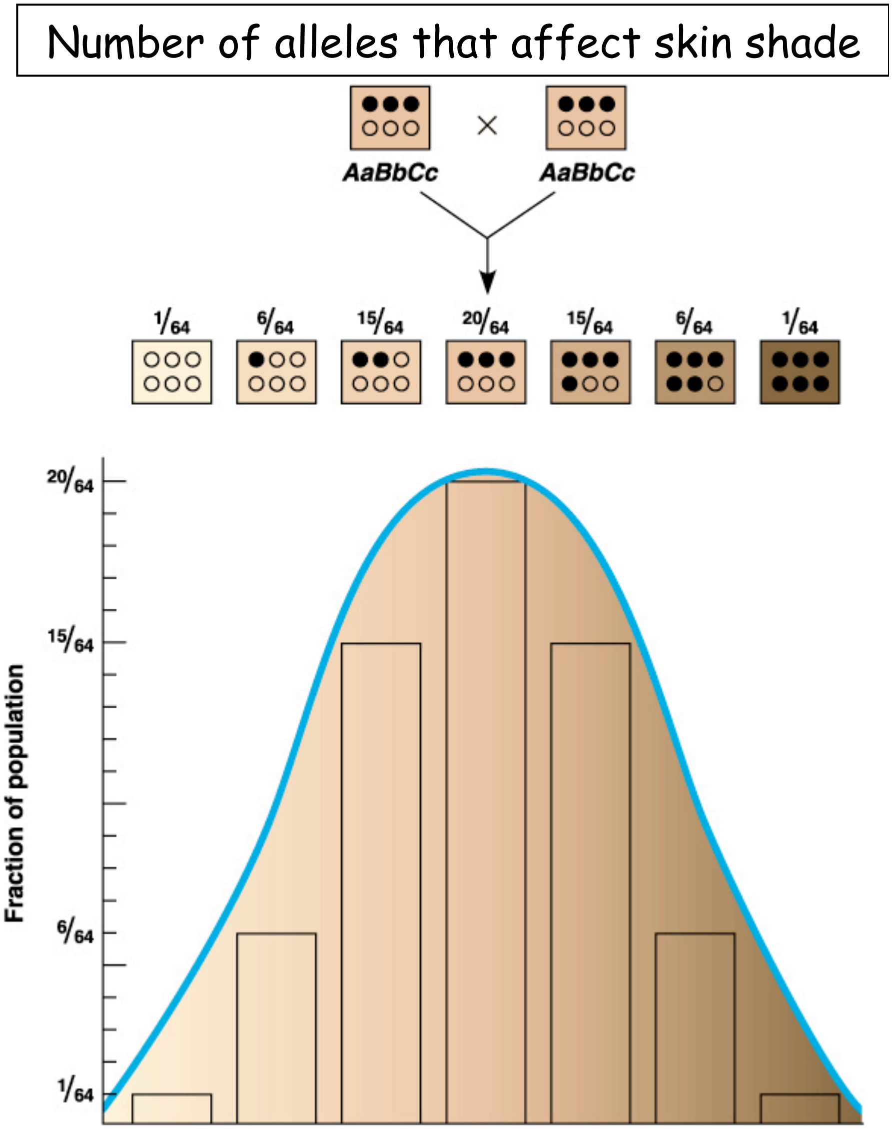
	Y	y
Y	YY dead	Yy yellow coat
y	Yy yellow coat	yy white coat

Gene Interaction

Polygenic Inheritance

Occurs when two or more genes affect one trait.

Polygenic inheritance is responsible for such traits as: **skin color, eye color & height**



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Polygenic Inheritance con't

Genes that mask the expression of other genes

- Example: **Coat color in dogs**
- B = black coat
- b = brown coat

ALSO

W = prevents pigment

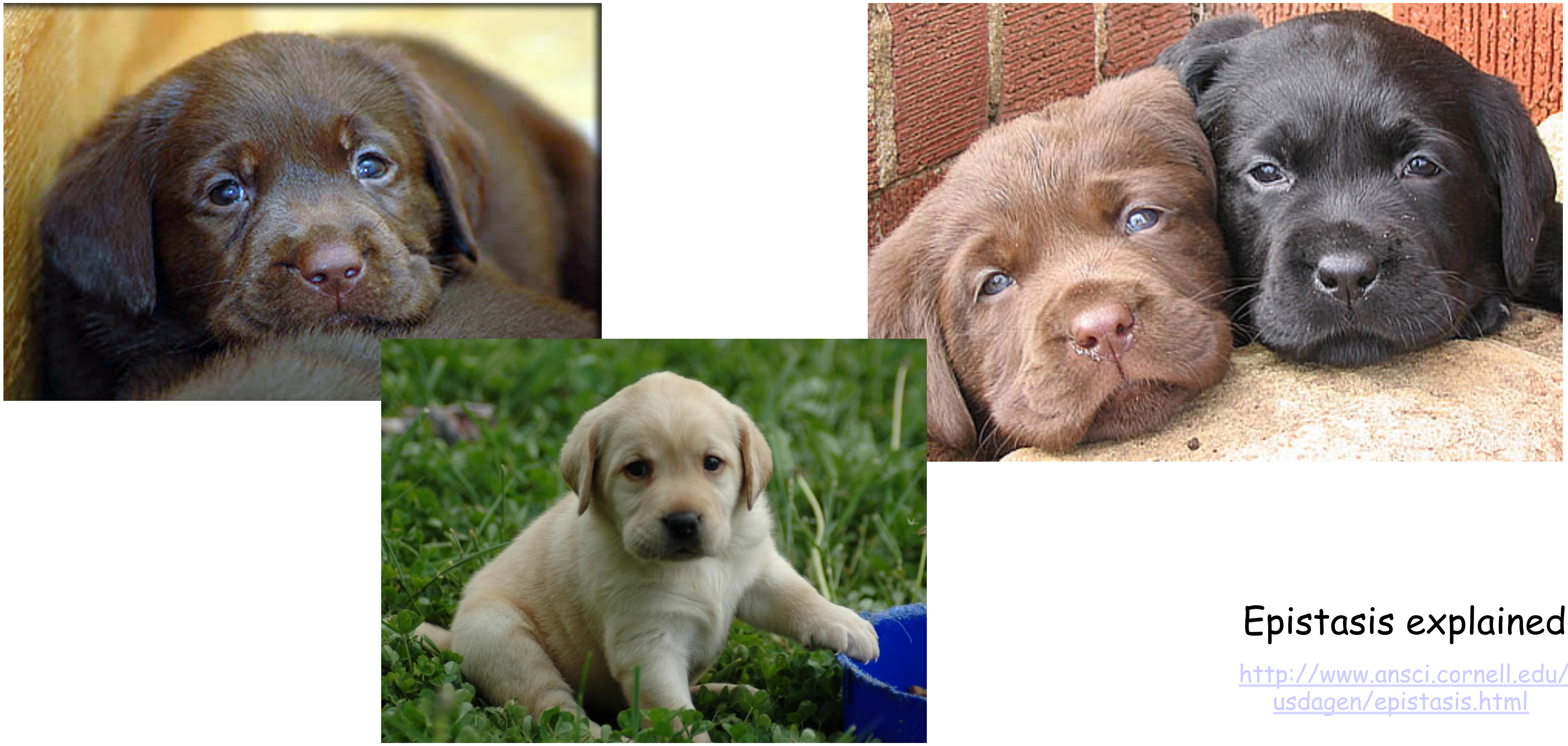
w = allows color

W is a separate gene located on a separate chromosome

W allele masks the effect of the B gene

Dog example continued

- wwBb genotype = black phenotype
- WwBb genotype = white phenotype
- wwbb genotype = brown phenotype



Epistasis explained

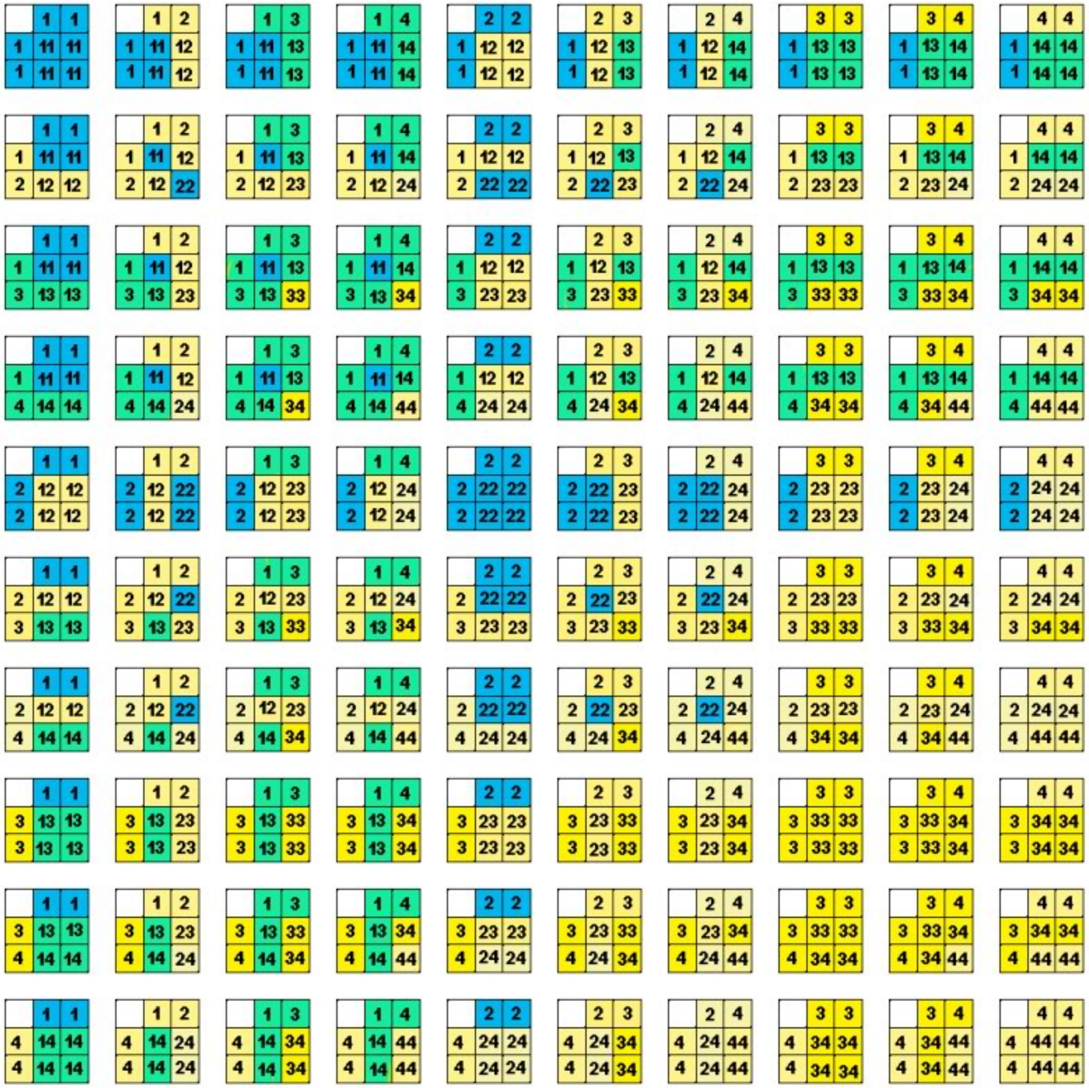
http://www.ansci.cornell.edu/usdagen/epistasis.html

Another example of Polygenic Interaction

genes combine to produce more feather colors

Polygenic Interaction

Combinations of 4 genes produce the various colors in parakeets.



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The yellowface trait is believed by many to be caused by various combinations of four genes:

1) the normal recessive white base gene
2) a similar yellow reducing gene called either yellowface mutant 1 or creamface
3) goldenface
4) yellowface mutant 2 - similar to goldenface but lighter

It is important here to note the difference between traits and genes as the sf yf mutant 1 produces the yf1 trait and the df appears as a normal, and the goldenface and yf mutant 2 genes may result in varying shades of the yf1 trait as well as the greenish yf2 trait. Extensive test breeding may be necessary to determine a bird's genotype for this trait.

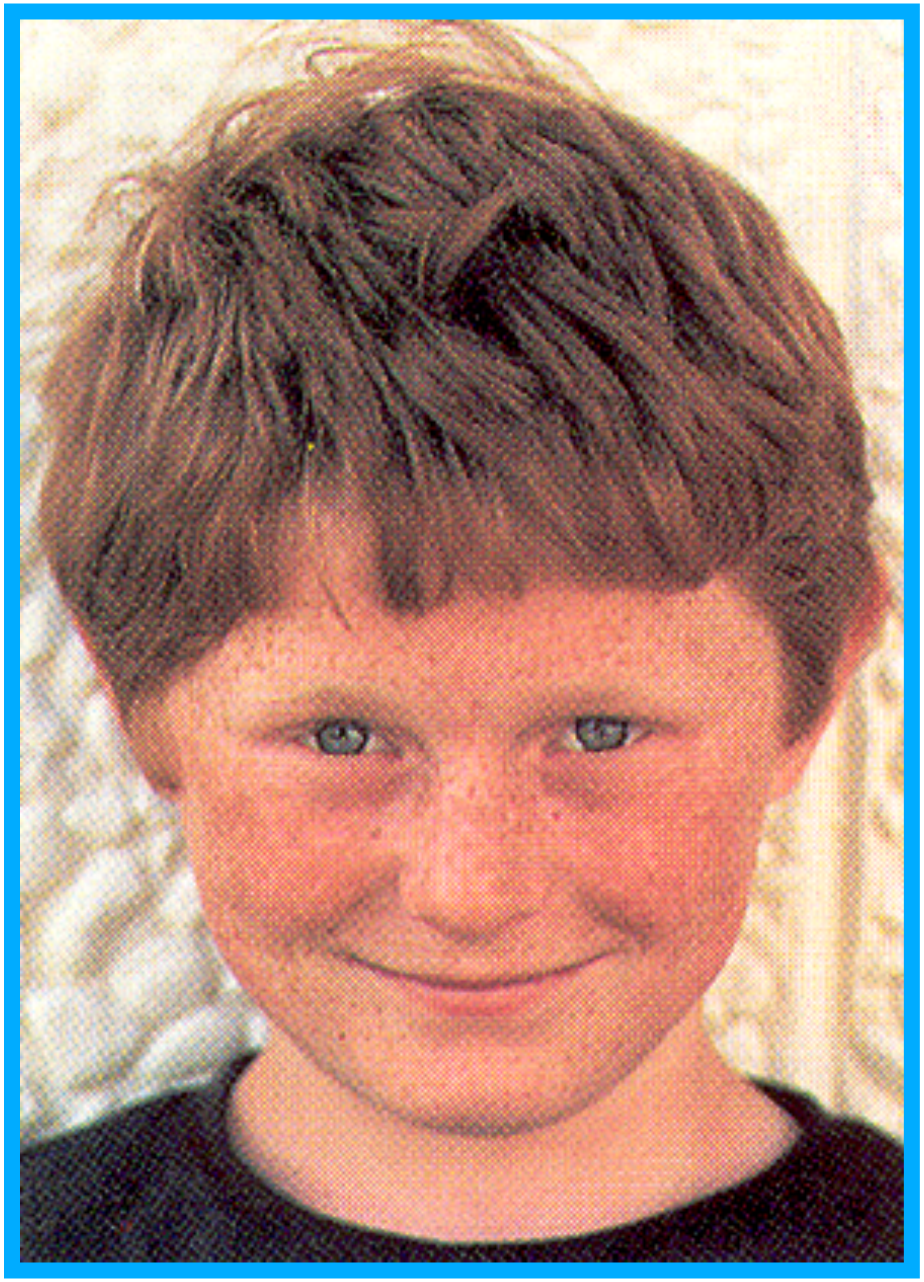
Environment and Phenotype

The environment can affect the way a phenotype is expressed.

- Primrose flowers
  - Red if raised at room temp
  - White when raised above 30 ^{0} C

Effect of Environment on Phenotype

Submerged leaves are finely divided, compared with the ones growing in air



Sun lightens hair
&
Darkens freckles

Give these a try. All are very good sites!

Genetics Problems 1:Dihybrid crosses
http://www.k-state.edu/biology/pob/genetics/dihy.htm

Practice Genetics Problems
http://www.k-state.edu/biology/pob/genetics/dihy.htm

More Practice!