Colour *and* Horn Condition...



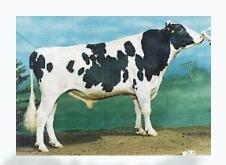








So, what happens when...





Black and White and Polled

Black and White **and** Polled



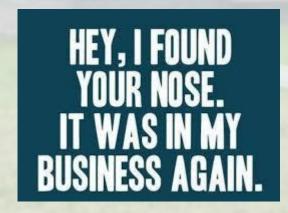
Genotypes?
Phenotypes?
Ratios?



Mendel's Second Law...

The Law of Independent Assortment

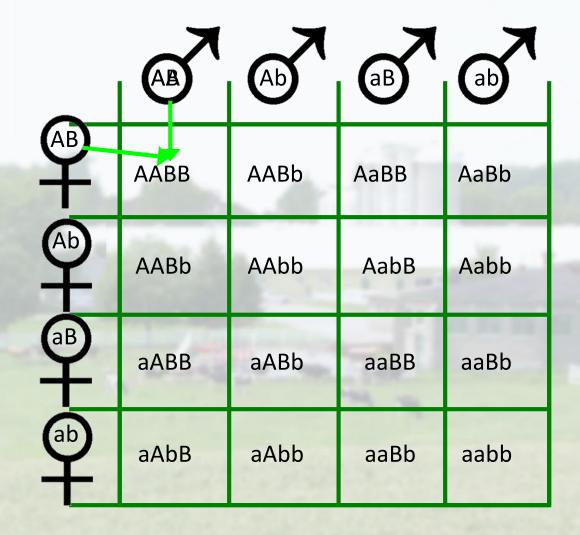
- Genes controlling separate traits segregate independently
- Segregation of genes at one locus does not influence segregation of genes at another locus





Punnett Square... again!

The "A" Gene and The "B" Gene



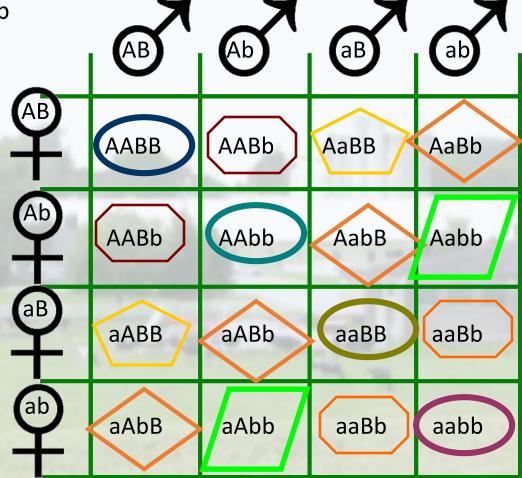


Assume that A > a and B > b

GENOTYPES?

1:2:1:2:4:2:1:2:1 RATIO

9 genotypes



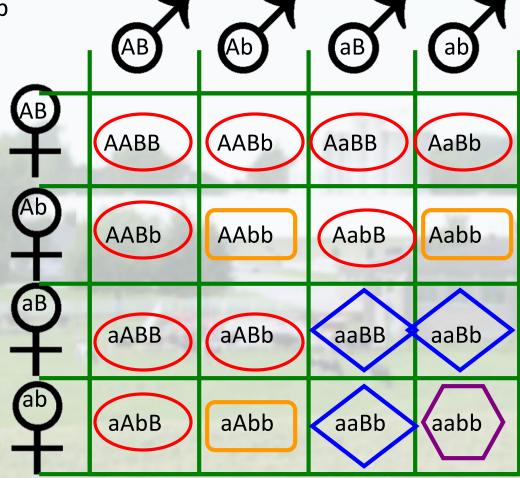


Assume that A > a and B > b

PHENOTYPES?

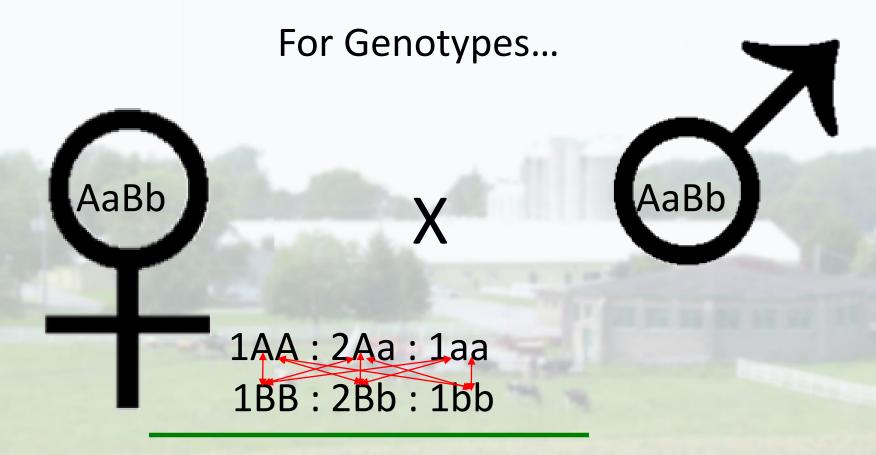
9:3:3:1 RATIO

4 phenotypes





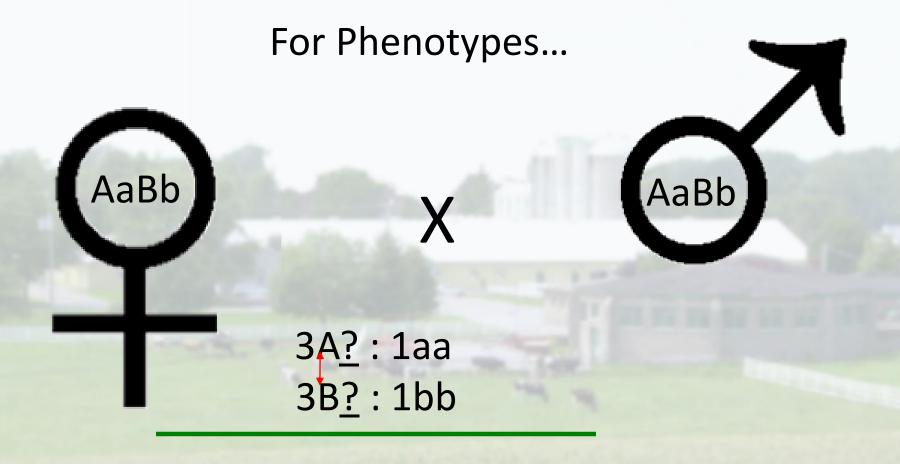
The Algebraic Method



1AABB: 2AaBB: 1aaBB: 2AABb: 4AaBb: 2aaBb: 1AAbb: 2Aabb: 1aabb



The Algebraic Method



9A?B?: 3aaB?: 3A?bb: 1aabb



Formulae for:

(assumes hybrid crossing, two alleles per locus and complete dominance)

eg, Aa	eg, AaBb	eg, AaBbCc	eg, AaBbCcDd
Χ	Χ	X	X
Aa	AaBb	AaBbCc	AaBbCcDd

Number of Traits / Number of Gene Pairs	1	2	ფ	4	•••	n
Number of Gametes	2	4	ω	16		2"
Number of Combinations	4	16	64	256		(2 ⁿ) ²
Number of Genotypes	3	9	27	81		3"
Number of Phenotypes	2	4	8	16		2 ⁿ

But even if those assumptions don't hold, Mendel's 2nd Law of *Independence of Events* will work



Shorthorn Cattle...











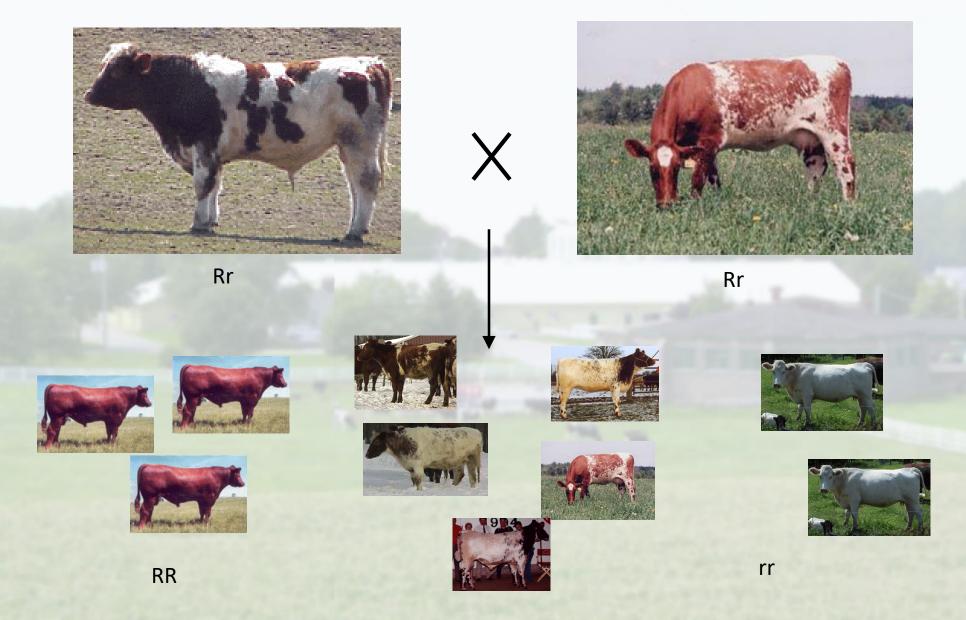








Monohybrid Cross





Coat Colour in Shorthorn Cattle... an example of Codominance

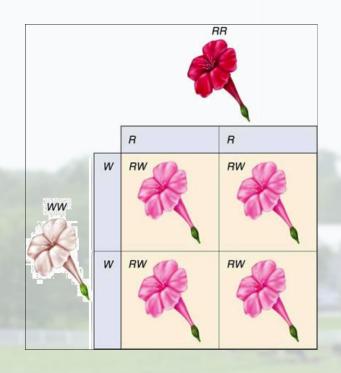




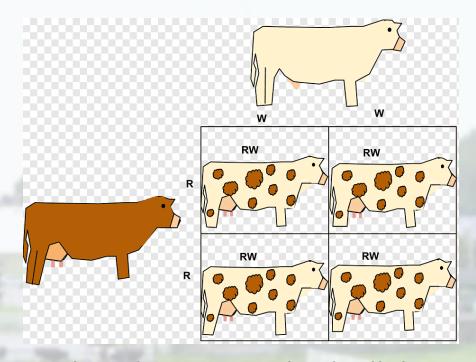
And we use the notation of R = r or R = W



Incomplete Dominance versus Codominance



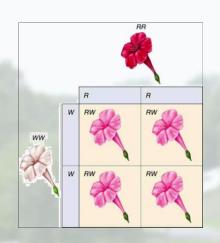
- With incomplete dominance, <u>neither</u> allele gets to express itself completely (e.g., there is *no* red and there is *no* white).
- Neither allele dominates



- With codominance, <u>both</u> alleles get to express themselves partially (e.g., some black <u>and</u> some white).
- Both alleles dominate



Incomplete Dominance versus Codominance



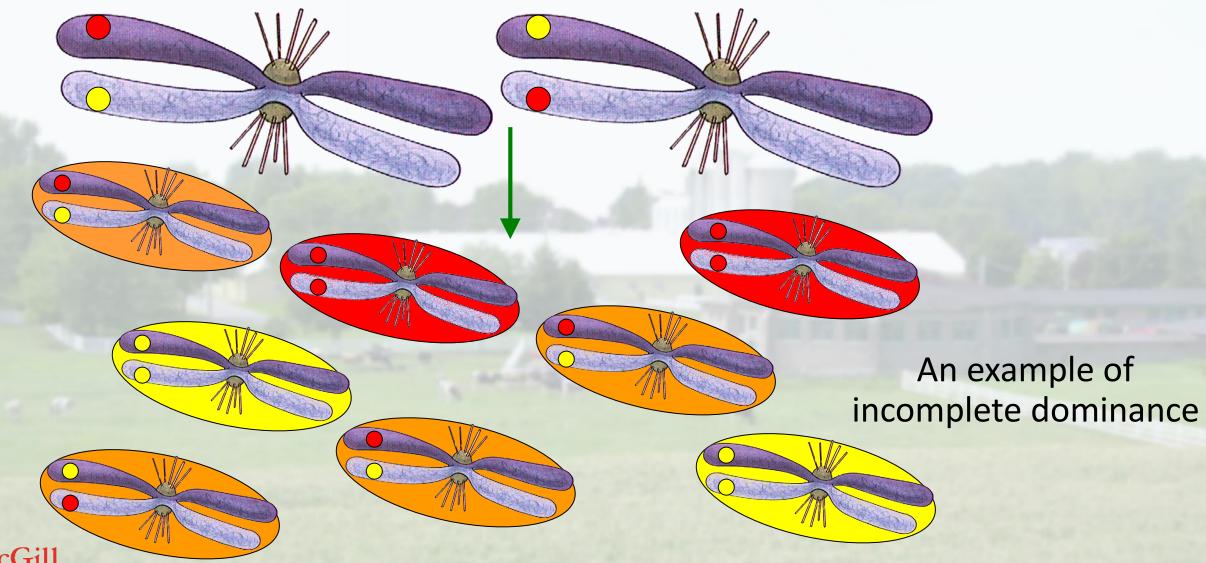




In both cases, the genotype is heterozygous.

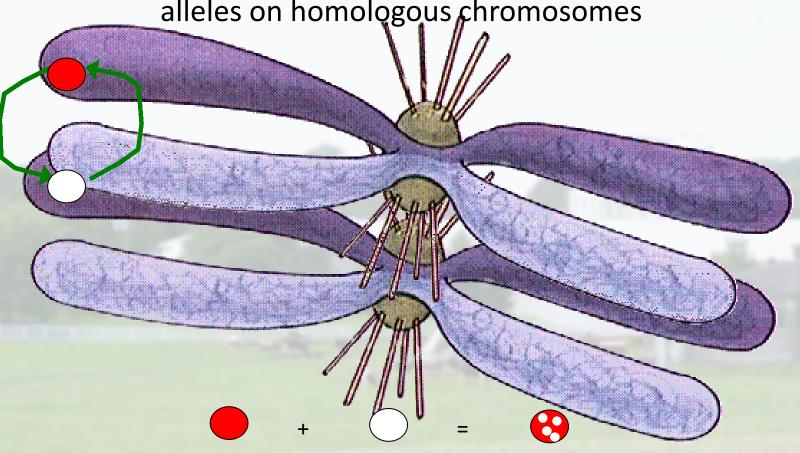


The Monohybrid Cross... again (but • = •)



Allelic Interaction

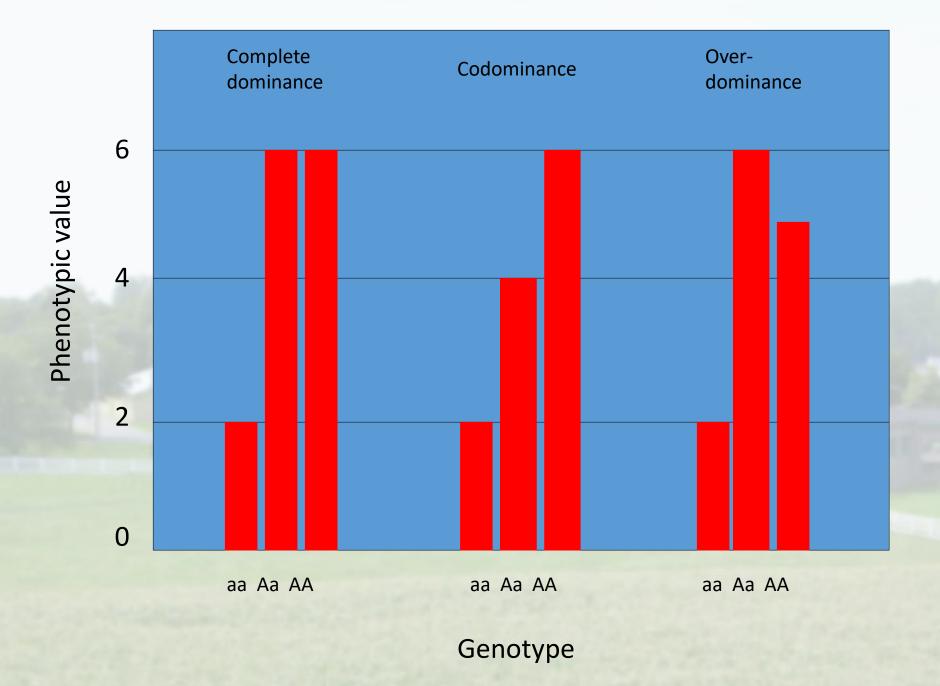
Interactions between corresponding alleles on homologous chromosomes



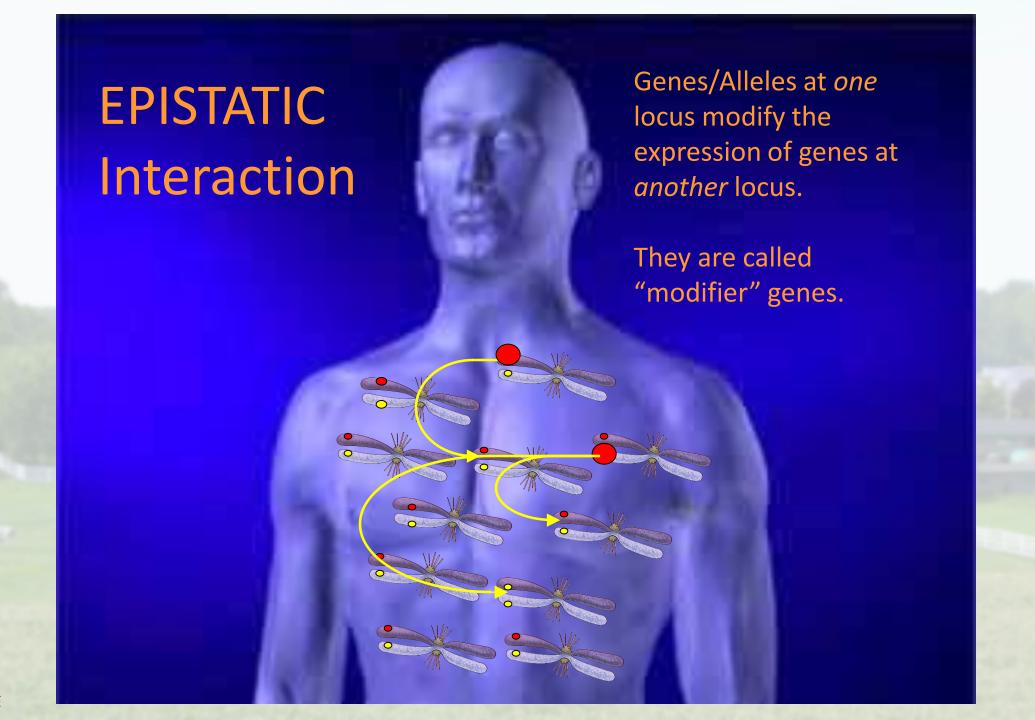
An example of codominance

Red (R) + White (r) = Roan (Rr)

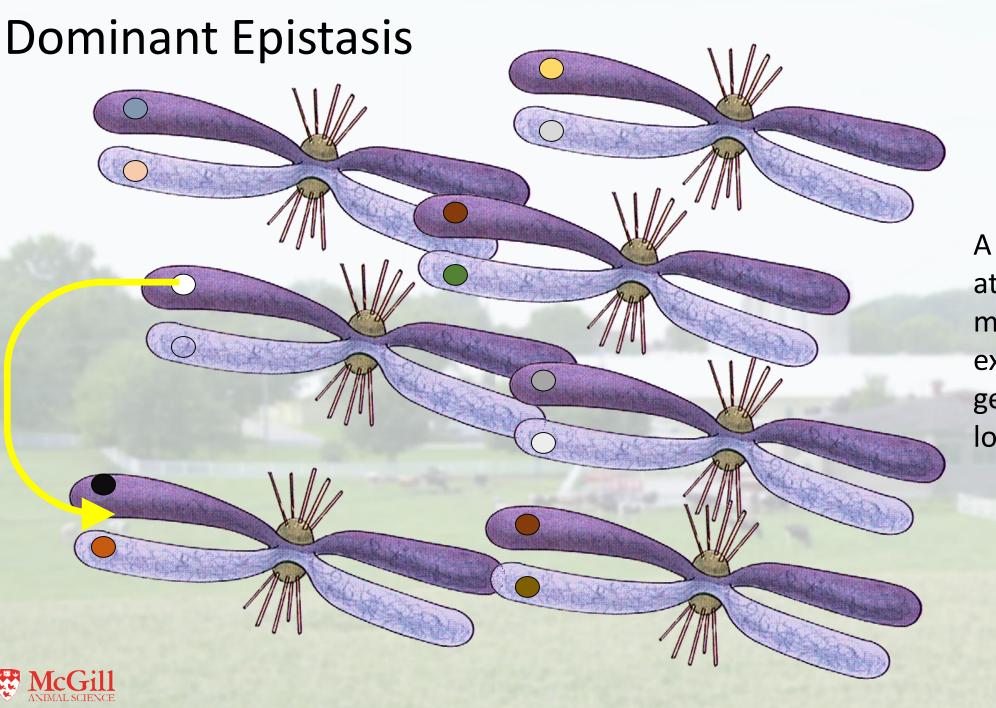












A dominant allele at one locus modifies the expression of genes at another locus



Bb Bb Ww Ww 9 W_ Chank Chank 12 white bb W_ 3 black В ww 1 brown bb WW



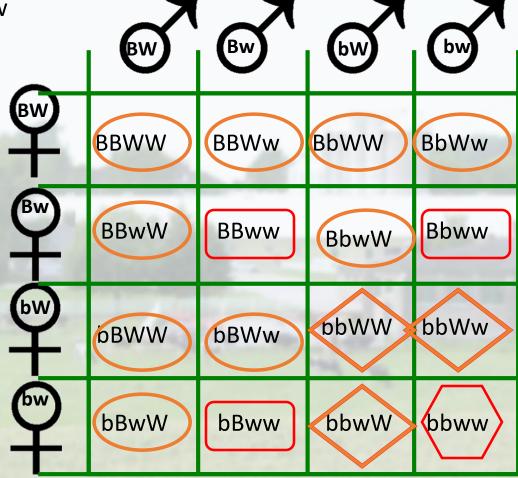
Assume that B > b and W > w

PHENOTYPES

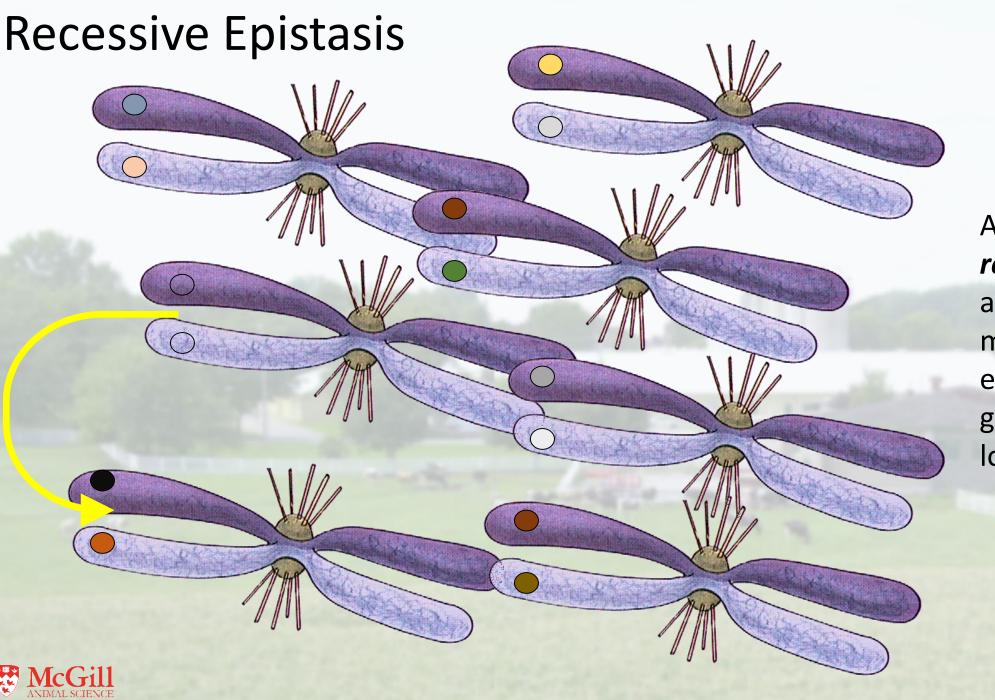
9:3:3:1

12:3:1

Because...
W_ dominates
all forms of
the B genotype

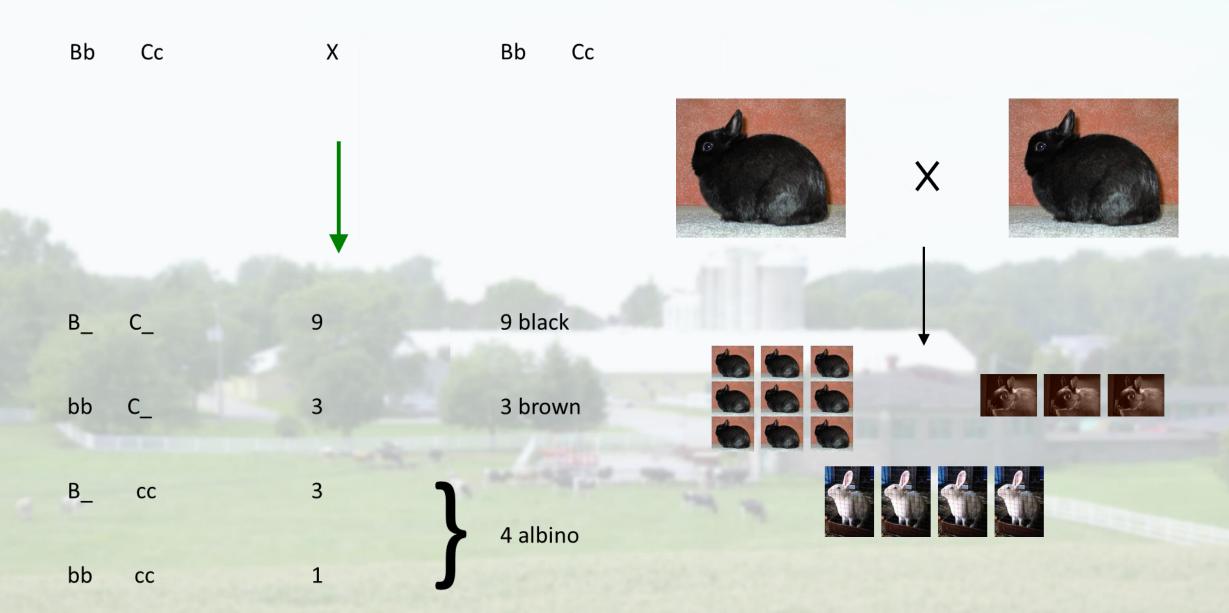






A homozygous recessive pair of alleles at one locus modifies the expression of genes at a second locus







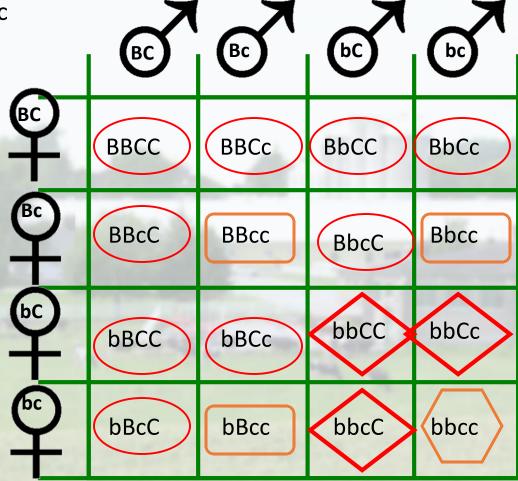
Assume that B > b and C > c

PHENOTYPES

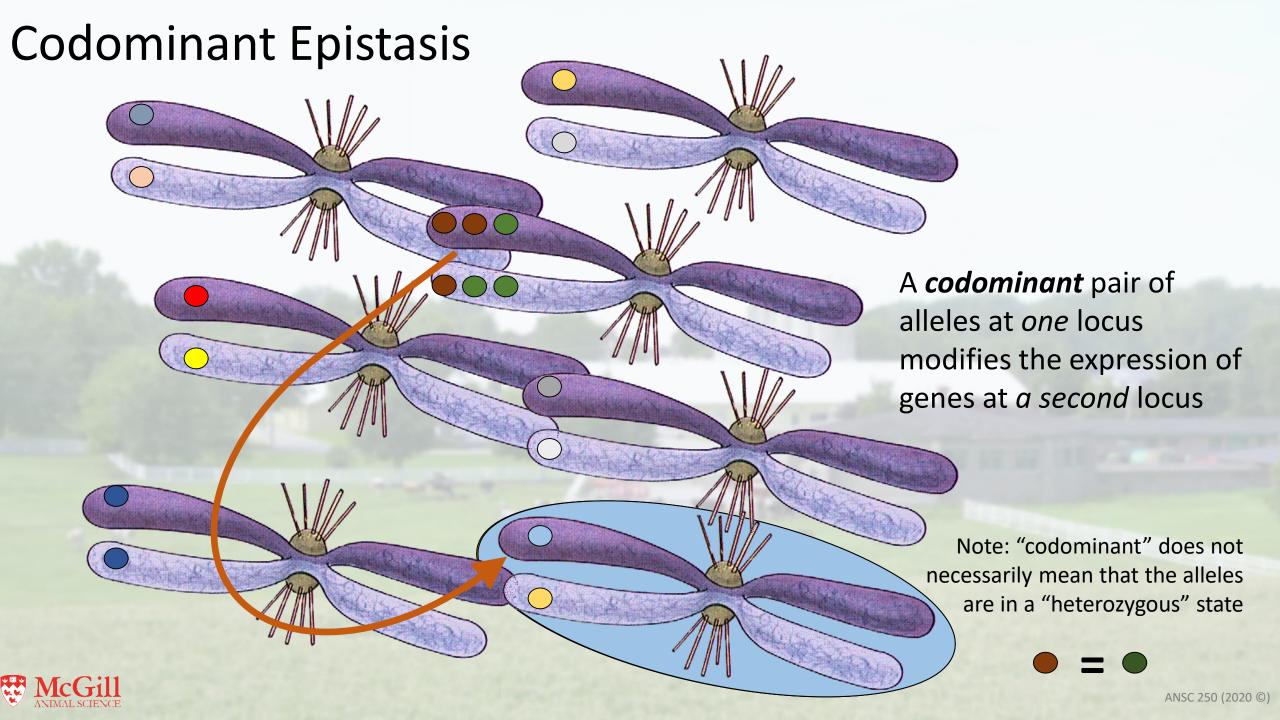
9:3:3:1

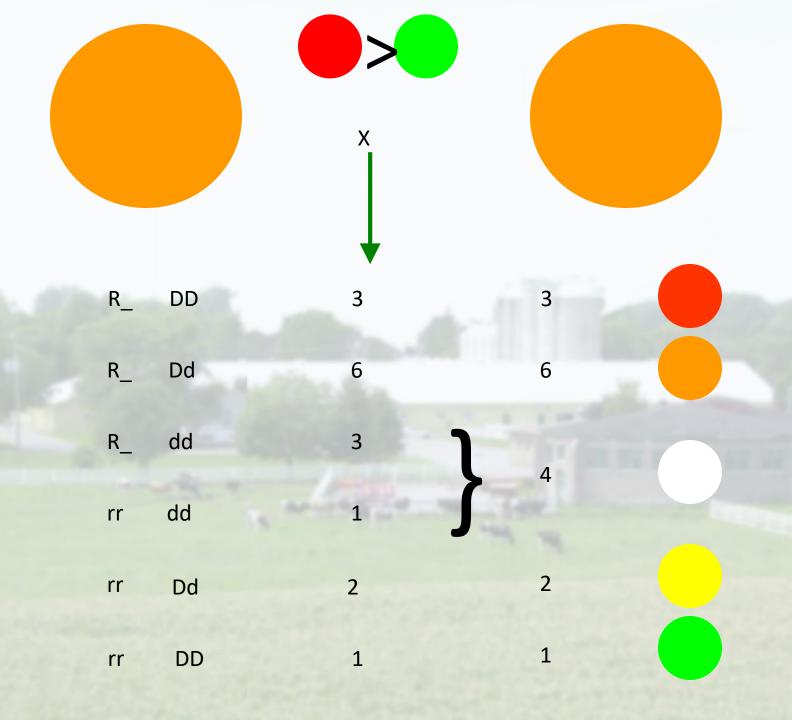
9:3:4

Because...
cc "dominates"
all forms of
the B genotype



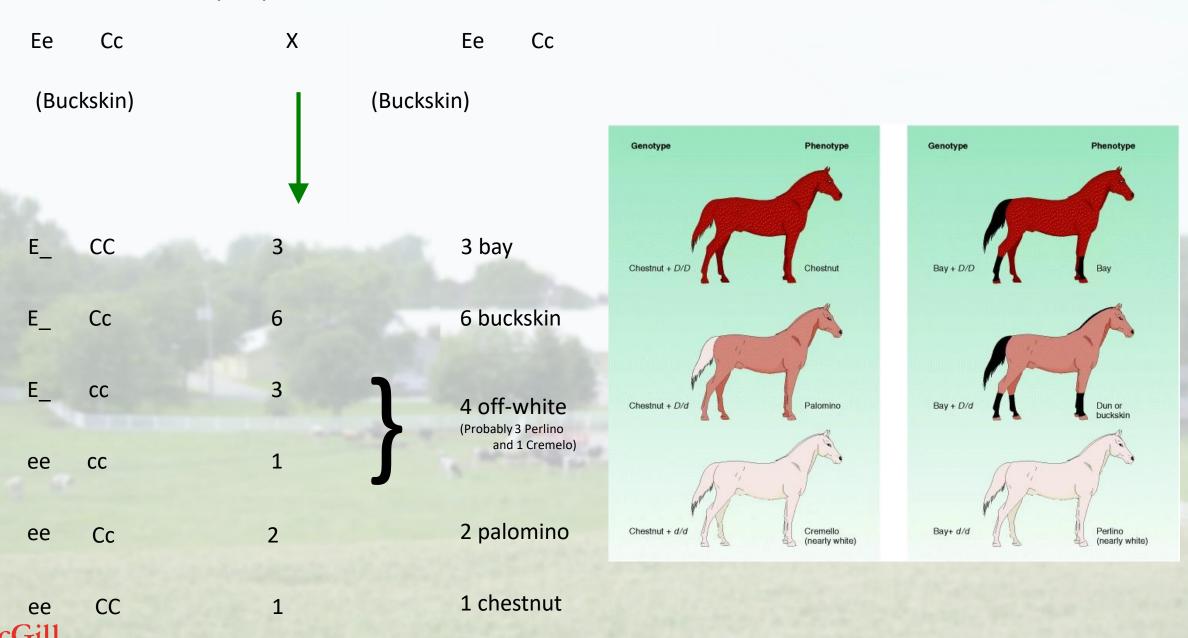




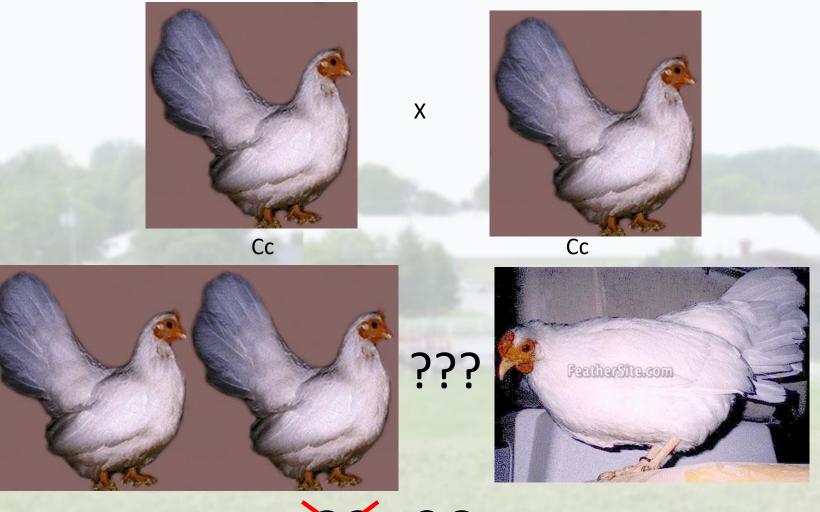




Normally, Bay is dominant to Chestnut



Creeper Condition in Poultry: Ratios don't add up!





CC: 2Cc: cc

Lethal Alleles...



Coat Colour in Mice



Creeper Condition in Chickens



Manx Cats (no tail)



Comprest Dwarfism in Cattle



A "lethal" condition arises when some allelic combination (e.g., mm) leads to an embryonic death, and so the resulting offspring (and its associated phenotype) is never observed, leading to an "unexpected" ratio (i.e., numbers don't add up to 4 or 16 or...).

Multiple alleles

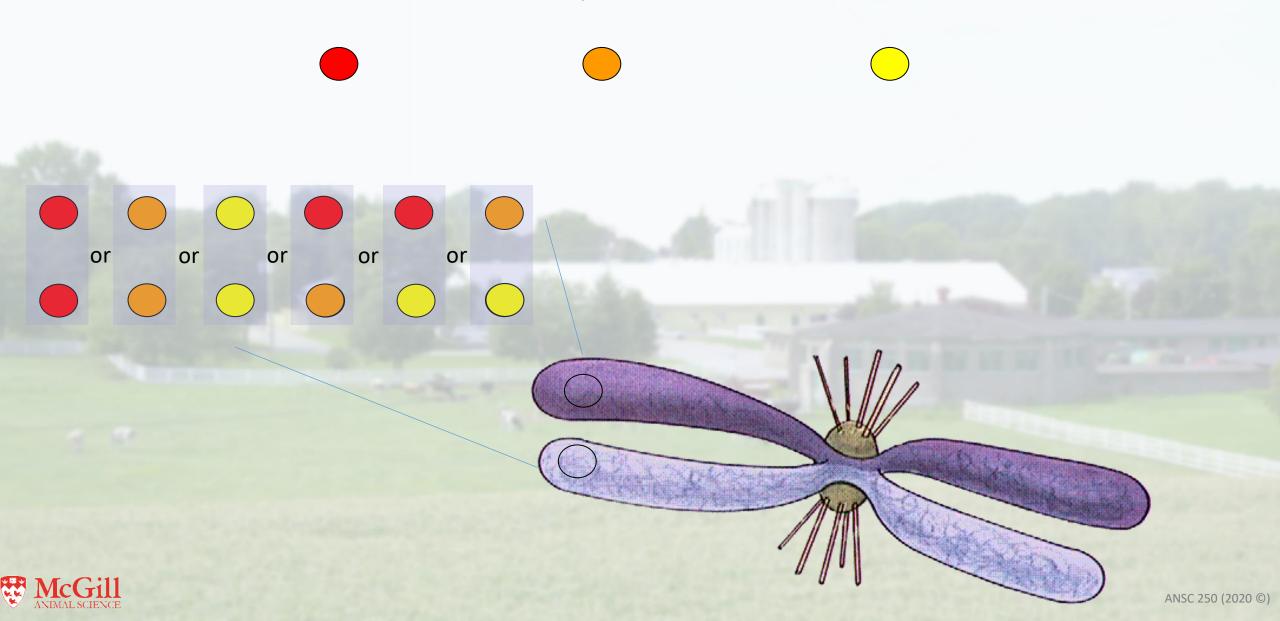
(refers to 3+ alleles available at any one locus)







Multiple alleles



Multiple Alleles - Blood Groups in Humans

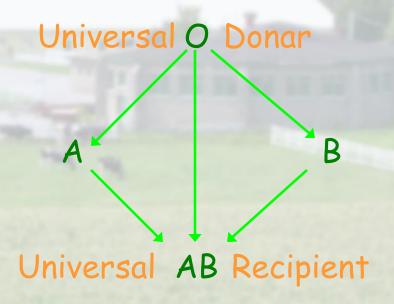
3 alleles (A, B and a)

$$A = B > a$$
 i.e., $A = B$

$$A > a$$

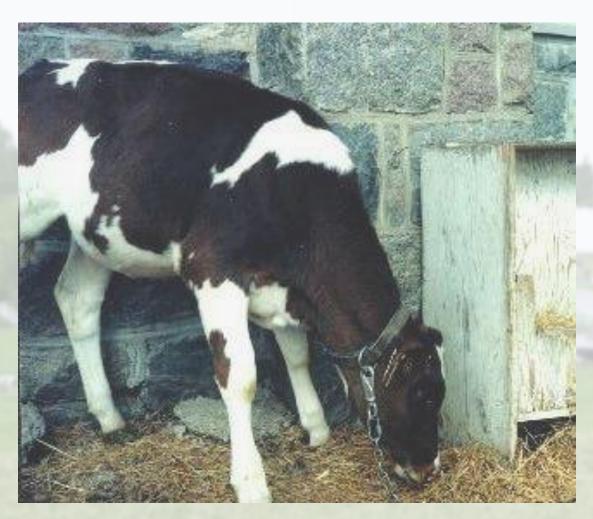
$$B > a$$

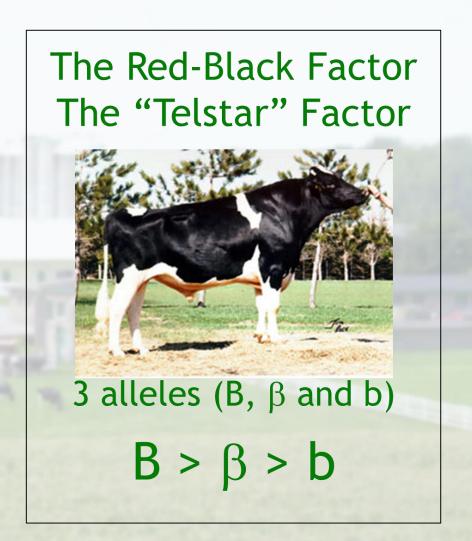
Genotype	Blood Group
aa	0
AA, Aa	A
BB, Ba	В
AB	AB





Coat Colour in Holstein Cattle... a closer look!









BB or BB or Bb = "True" Black & White

ββ or βb = Red-Black Factor

bb = Red & White

Bb

Is there a cross that can give all 3 phenotypes?

Why is this *not* a case of codominance?

2 Black & White 1 Red-Black & White 1 Red & White



For more information (not for the exam!!)

The Various Mechanisms

of Red Colour Transmission in the Holstein Breed



nly animals of Black and White (B&W) est black and white cow. A red calf best black and white cow. A red cail would be disposed of and not a word of it would be mentioned to the neigh-bours. Later on we saw some bulls sold for A.I. and then returned to the original owner because of the arrival of a red calf. It is easy to conclude why the opulation dropped drastically at that

The bull A.B.C. Reflection Sovereign which carried his red factor) were at heir peak in the 1960s, Rosafe Citation R, Roeland Reflection Sovereign, Rosafe ino and Chambric A B C were Domino and Chambric A B C were among the most well-known. It became an irresistible force to have their our-standing red offspring retained in the breed. For the first time in 1969, red animals became eligible for registration in the Holstein herd books in Canada and the U.S.A. Almost all animals carrying red today can be traced to A.B.C. Reflection Sovereign, and he can dearly be considered as the father of the modern-day red Holstein breed. In his

articles Doug Savage concluded that the percentage of *RC in the population, in spite of the fact that it was at its lowest back at the level of 25 percent where it

THE ACTUAL PICTURE

had turned almost black. It is important Internationally, this popularity is at a to underline that "Triple Threat" was also a true red carrier. This true red the red gene into their best B&W cow in the pedigree, have contributed to the spreading of this factor in the popuand *RC bulls available in A.I. One thing remains for sure becare have noticed it in our own her

TRADITIONAL RED COLOUR

simple. The black colour (B) is dominant and the red colour (r) is

true Red & White calves if mated to a R&W (50 percent of the time) or an *RC cow (25 percent of the time, e.g., *Rubens*). A (IRR/t) bull has the Black/Red colour himself and is a *RC. He can give true R&W calves if mated to a R&W (50 percent of the time) or "Triple Threat" and "Boy George" Finally, a (rr) bull is R&W and can give

(100 percent of the time) and when mated to a 'RC cow (50 percent of the time), (e.g. 'Redman'). These explanations may seem sim-plistic to some of you, but in the course of my travels I meet hundreds of breeders a year and I am always surprised to discover that these bas

we have noticed it in our own berdin Black is dominant to Black/Red and to Red; and Black/Red is dominant to Red. in other words, a (181) ball is Black & White and will never produce a Black/Red calf nor a Red calf. A

(B/BR) bull is Black & White and is a *BR carrier. He will never give a true

rue Red & White calves if mated to

hem, because black is dominant on red to the genotype for the colour on thi black animal can be (BB) or (Br), thi ast one being a *RC animal. Chart #1 shows all the possible genotypes for all

calves that would turn almost totally

black after a few months of age This specific colour would be name

Surinam Sheik Rosabel, Many genetic R&W cow, she was sired by a R&W Black, *RC or R&W. At least two of her Treasure (by "Astro Jet") at United "Marquis Ned") at Trans-World Genetics. A very surprising effect was noted in red descendants of Rosabel (males and females): they could pro-

simals should have been Black &

So why were they Red & White? So why were they Red & White? Based on a great deal of research into the coat colour of offspring from members of this family, especially Treasure* and Trazarra*, it is very clear that Rosabel is a carrier of a second mechanism of colour transmission that works totally independent of the traditional one, and is passed on to the traditional one, and is passed on the traditional one, and is passed on the traditional one. to the next generation 50 percent of

black/red. When a R&W *VR (variant

noted in red descendants of Rosabel (males and females), they could pro-duce Red & White offspring when mated to Black & White (BB) and Black & White offspring when

mased to Red & White (ee).

which brings the black, the red or the ed carrier) bull is mated to a BAW cow red carrier) bull is mated to a B&W cow (BB) and the 'Wk is passed (50 percent of the time), the calf is R&W 'W bull does not pass the 'Wk 'G0 percent of the time). When the R&W 'Wk bull does not pass the 'Wk 'G0 percent of the time), the traditional mechanism of colour transmission will determine the colour of the calf.

makes us think that this very rare amilies. Chart #2 shows all the possible lamilics. Chart #2 shows all the possible genotypes and all the colour possi-bilities when we use a R&W bull (BB 'VR), c.g. "Treasure", on R&W (BB), B&W 'RC (BP) or R&W (rr) cows. "YR (Red) stops the expression of the B (Black) and the r (Red). This chart is based on the results of research made | SLACK | COW | SI | Sharp | S

A bull sampled in the United States, Maple-Vane Surprise-Red *BC (Carrier of Hlack), produced similar results in the 1980s. More recently, his grandson Sunset-Acres Equi-Red-Tw (Ric, has done the same. Thece two bulls are apparently not related to Rousel. This red R&W from the "VR and R&W fro

ossibilities when using a R&W bull *VI

	1	Black	Their	-	fiel	Ш,	Щ	1		•		952	BALL	1110			
BLACK	N	B	BVR	B	BVR				BLACK	X	В	BVR		rVR			
COW RED B SS Stock S CARREST F Stock S	8	Stack	Book	Disch	SSVn fiel	4/6		50% RED	COW	8	Stech	SQUIT Fact	Disch	Britt field	4/8		50%
	1 8 170 Dec	e de	rgun. fred	-	Ē	HED		8	\$10 Shack	SQL:T	Deck	Brich. fied			HED		
ace.	N	8	BVR	8	8VR	П			BLACK	N	8	BAB	r	rva	П	Π	1
COM	r	glack Sheck	Pun	2	rgyn fied	4/9	_	SON. RED	CARRIER	8	89 Stech	BByn Fed	Deck	@ryn Ned	s/a		62.55
	r	7 (Back 7	A Feet B	-Q Date:	r@cit had			RED		r	2	₩n feet	ñ.	17975 Dark	-		RED
16.75	100.00	· tem	ibet -	-	or the	ford fo				N	8	BVR	r	rVR	Г	Г	Г
R is v	32.9	sed (on or	nly 5	io per	roce	t o	f the	COM	r	State	r@sm Feet	red	nvits Red	6/9		75%
ame i										r	12	20	Sed	11-1575 The d	-	-	Hair
rhy w Treasu VR con nd the scans	he he re',	n st we was r	ons. udyi sec mate ing	ng to	he p s wh a R8 was	the rog w Ba	en a l bull W,	y of R&W I (m) This	This percen percen coat co he is n	t ol	& W f the r or	(who	e) n	VR is egan type	iles of t	nne n oi he	d 50 f the

This bull should theoretically sire 50 percent R&W (when "VR is passed 50 percent of the time) regardless of the coat colour or the genotype of the cows he is mated to. When "VR is not passed also being a carrier of the traditional rec-factor (*RC), the colour transmission

"Mutant" should have been Black & of animals known to be carriers White. However, being R&W, it is very clear that he is also a "VR (carrier of the this research should fully explain all the

Researchers Identify the "Dominant Red" Gene in Holsteins

A team of researchers were recently successful in identifying the specific gene responsible for causing red coat colour in Holsteins, commonly referred to as "Variant Red", which is distinctly different than the longstanding traditional recessive red gene. This significant outcome is the result of a research project funded by the Dairy Cattle Genetics Research and Development (DairyGen) Council of Canadian Dairy Network (CDN) on behalf of industry partners involved with dairy cattle improvement in Canada.

The first known expression of the "Variant Red" gene occurred when Surinam Sheik Rosabel-Red (HOCANF3541221) was born on October 21, 1980 and neither of her confirmed parents were carriers of the recessive red gene traditionally responsible for producing Red & White Holsteins. As the original source of this gene, Rosabel-Red is the oldest animal to which Holstein Canada has assigned the codes of "RW", as a Red & White animal, "VRC" as a carrier of the Variant Red gene, and "BKC" to indicate that she also carried the gene responsible for Black & White coat colour.

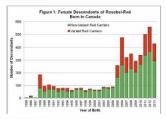
In total, Rosabel-Red produced 30 progeny registered by Holstein Canada of which 15 were born Red & White, clearly reflecting that this source of red acted in a "dominant" nature over the Black & White gene. To date, there have been over 5,000 female descendants of Rosabel-Red born and registered in Canada with the voungest being as far as 11 generations away. In terms of male descendants, the current tally exceeds 150 born in Canada plus another group of at least 75 bulls born in other countries. Rosabel-Red now has descendants born in at least 12 different countries suggesting that her "Dominant Red" gene has crossed many international borders as a source for

Successful Research

In 2011, the DairyGen Council of CDN approved funding for a research project led by Dr. Graham Plastow at the University of Alberta in collaboration with Dr. Ben Dorshorst (Uppsala University in Sweden and Virginia Tech in Blacksburg, VA, USA) and Dr. Leif Andersson at Uppsala University. A variety of significant factors contributed to the from a handful of breeders in Canada and the United States that owned animals that carried the gene of interest. In fact, within one herd there was a single half-sib family (i.e.: daughters of one carrier bull) that had 15 "Variant Red" animals and 17 Black & White animals. By genotyping the sire in guestion, these 32 daughters and their Red" gene. The database of genotyped animals and their pedigrees at CDN was used to identify other families of interest for genotyping. All genotyping for this research initiative was coordinated through Holstein Canada and all costs were covered by the In the end, the research team was able to identify the exact causal mutation responsible for the "Dominant Red" gene in Holsteins and confirm its mode of transmission. This gene acts totally independent from the traditional recessive red gene known to yield red coat colour in Holsteins. The fact that it behaves in a dominant manner over the gene responsible for Black & White coat colour makes it much easier to obtain Red & White Holsteins, if desired. To date, all breeding age animals have been carriers of only one copy of this "Dominant Red" gene, meaning that, on average, 50% of their progeny would be born red. As interest in this gene increases as a source of producing Red & White Holsteins, the development of a homozygous "Dominant Red" carrier would be possible and such animals would produce red progeny 100% of the time, regardless of the colour of the other parent.

Carriers of "Dominant Red" Gene

Figure 1 shows the count of female descendants of Rosabel-Red in Canada by year of birth with 2013 still being incomplete. Carriers of the "Dominant Red" gene have traditionally been labeled by Holstein Canada as *VRC, meaning Variant Red Carrier. Although the number of active heifers and cows in the Canadian Holstein population that carry the "Dominant Red" gene is still relatively small, at just over 600, there is now a huge potential for breeders to take advantage of this gene for producing Red & White Holsteins. Without any high ranking proven sires that carry the "Dominant Red" gene, breeders can use the CDN web site query to find dozens of young sires that have a Parent Average or Genomic Parent Average over 2500 LPI. On the female side, the highest "Dominant Red" cow surpasses 2800 LPI while the most elite heifers have reached the 3000 LPI mark.



Future Testing for Carriers

As an outcome of this very successful industry-funded research effort, this discovered gene responsible for "Dominant Red" in Holsteins will be added to future genotyping panels, similar to the existing test for the traditional recessive red gene. This new test will become part of the publicly available results for animals genotyped with these

upcoming panels. Given that the "Dominant Red" gene is automatically expressed by producing a Red & White animal when it carries at least one copy of the gene the genotyping test will be most valuable for identifying animals that possess two copies of the gene (i.e.: homozygous) and for identifying carriers of the "Dominant Red" gene when both parents of the animal are carriers of the traditional recessive red gene.

For 15 years now, the DairyGen Council of CDN has allocated funds to industry priority research projects carried out in universities and research institutions across Canada. These funds are collected as part of the service fee structure applied to A.I. organizations, breed associations, milk recording agencies and Dairy Farmers of in Holsteins, which has existed for over 30 years, was highly successful. Going forward breeders in Canada and worldwide will be able to select for Red & White Holsteins in a much easier way and the genetic potential of carriers of the "Dominant Red" gene, labelled as *VRC for Variant Red Carrier, is rapidly increasing.

Brian Van Doormaal December 2013

Researchers Identify "Dominant Red" Gene Holsteins Doormaal. Canadian Network, December 2013. (click article for link).

I had, along with Roy MacGregor and coding system at Holstein Canada. This committee worked very hard, along with industry personnel and Holstein between the red brought by the 'y, the green and the red brought is offered a construction of the traditional recessive red gene. These actions were taken in order to provide the best available information to breeden interocled in developing led a despire information to orable breeden

swered questions we still have on | • given the existence of the 'VR code given the existence of the "R code in a pedigree of an animal, a "R gene/allele free determination is required for discontinuation of the secondary code and inclusion of Red in the name. (DNA test not currently available);
 reactivation of the "BC secondary code already done in 2006, in order

code already done in 2005 in order to fully cover the transmitting pattern of the "VR animals who are carriers of the Black (B).

CONCLUSION

Red (VG-87-DOM-12*), Leduc not Red (VG-87-DOM-12*). Leduc now works on a para-time basts performing consultant visits on member farms for Centre d'insemination arrificielle du Québec (CAQ). He is also a founding member and resource specialis for ibe Canadian Red and White Holseth Club.

Business Development Staff

The various mechanisms of Red Colour Transmission in Holstein Breed by Maurice Leduc. Holstein Journal, May, 2006 (click article for link).

the calf and its effect in this case is now gone. We also see cases where the "VR was passed to four consecutive gener-

ations and then when a R&W bull (rr) was used for the fifth generation, the resulting calf was B&W. This means the

this is why the actual DNA coat

A young bull available from GenerVations

A young bod available from GenerVasions today draws attention to this unusual mechanism of colour transmission once again. He name is Belehaven Champions Mutann. He is sired by "Champion" (IIII) from a daughter of "Freasure" (the son of Rosabel). Based on the traditional mechanism of colour transmission,

http://www.genefix.it/docs/Red Color Transmission eng.pdf

https://www.cdn.ca/document.php?id=339

Formulae for numbers of...

(assumes hybrid crossing, two alleles per locus and complete dominance)

Number of Traits / Number of Gene Pairs	1	2	3	4	 n
Number of Gametes	2	4	8	16	 2"
Number of Combinations	4	16	64	256	 (2 ") ²
Number of Genotypes	3	9	27	81	 3"
Number or Phenotypes	2	đ	8	16	 2"



Coat Colour in Foxes

(Simplified)

3 alleles: S, s, and p How many combinations?

$$(S = s \text{ and } S = p)$$

SS = Silver

Ss = Platinum-Silver

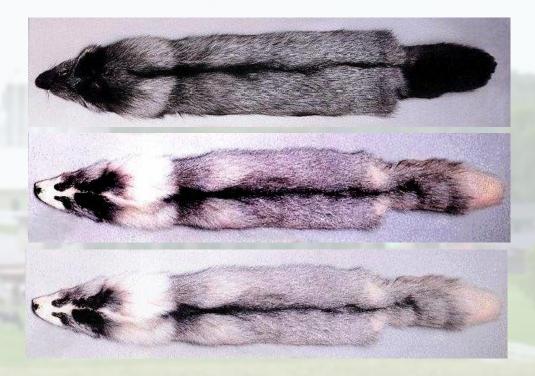
Sp = Platinum

SS

sp

Letha

pp













Remember...
PEA comb is dominant to SINGLE comb





Rose comb



Pea comb



1 : Walnut



1 Rose



1 Pea



1 Single









Walnut comb

Walnut comb



9 : Walnut



3 Rose



3 Pea



1 Single



What is the mode of inheritance?

RrPp X RrPp

Phenotypes	Genotypes	Frequency
Walnut	R_P_	9/16
Pea	R_pp	3/16
Rose	rrP_	3/16
Single	rrpp	1/16



Sex-influenced Inheritance

- Genes are found on the autosomal chromosomes
 - exactly like all the others so far
 - sex-influenced is **NOT** on the sex chromosomes
- The phenotype of the heterozygote is determined by the <u>sex</u> of the individual, mainly because of differences in the presence of certain hormones

AA aa Aa



Baldness in Humans — an example of a sex-influenced trait

Genotype	Female 🕄	Male &
B ⁺ B ⁺	Bald	Bald
B ⁺ B ⁻	Full Hair	Bald
B ⁻ B ⁻	Full Hair	Full Hair

So, in Females, Full Hair is dominant to Baldness but in Males, Baldness is dominant to Full Hair



Sex-influenced Traits...

• Examples in livestock...

 Horns are normally dominant in male sheep and recessive in female sheep

 The "beard" is normally dominant in male goats and recessive in female goats







Coat Colour in Ayrshire Cattle...



MM Mahogany



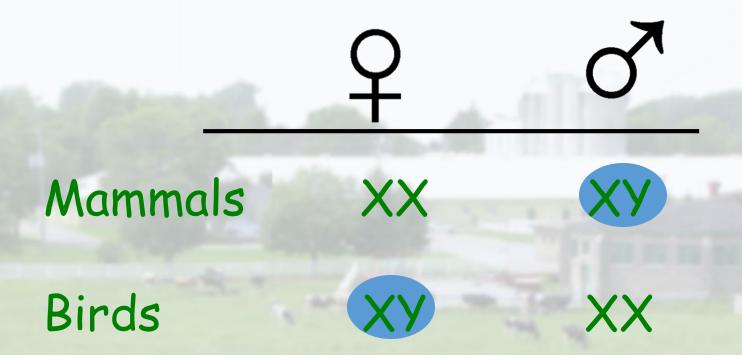
mm Red



Note: This does <u>not</u> mean that all MM are males or all mm are females

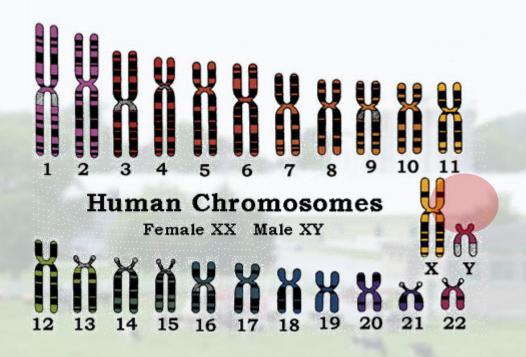


Sex Determination





The Sex Chromosomes are NON-homologous



Some traits have homologous counterparts and are expected to behave like traits on homologous chromosomes

Some traits do not have a counterpart



Notation change for sex-linked traits...



AA becomes

 $X_A X_A$

X₄Y

aa becomes

XaX

X

Aa becomes







Birds





Sex-linked traits

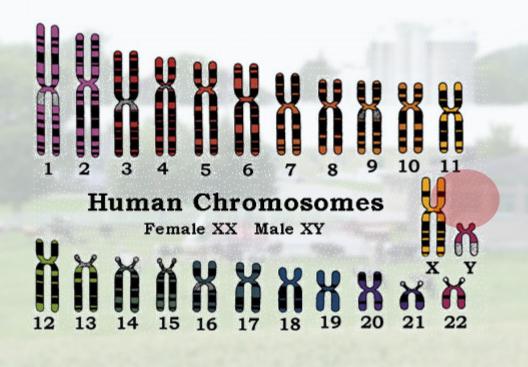






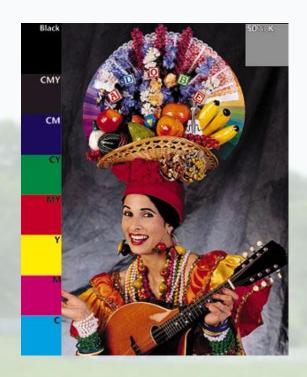
Sex-linked Inheritance

(traits with *no* homologous counterpart on the Y chromosome)





Colour-blindness in Humans



N > n

If the trait were inherited on homologous chromosomes...

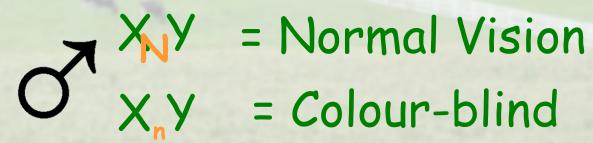
N_ = Normal Vision

nn = Colour-blind

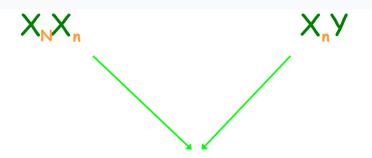


But since the trait is sex-linked...

A = Normal Vision A = Colour-blind



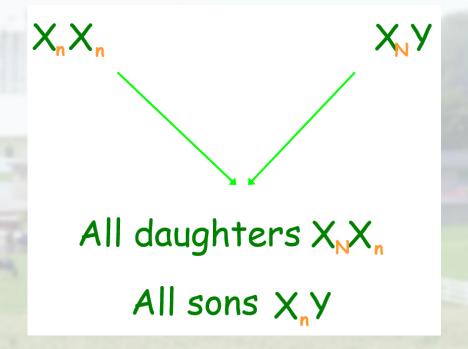




 $\frac{1}{2}$ daughters $X_{N}X_{n}$ $\frac{1}{2}$ sons $X_{N}Y$

 $\frac{1}{2}$ daughters $X_n X_n$ $\frac{1}{2}$ sons $X_n Y$

So, $\frac{1}{2}$ the *children* are colour-blind and $\frac{1}{2}$ the *children* have "normal" vision





Tortoiseshell coat pattern in Cats An Example of Sex-linked Inheritance



Black



Tortoiseshell





Orange

$$X_BX_B = Black$$

$$X_{R}Y = Black$$









All female kittens X_BX_b

All male kittens X_BY

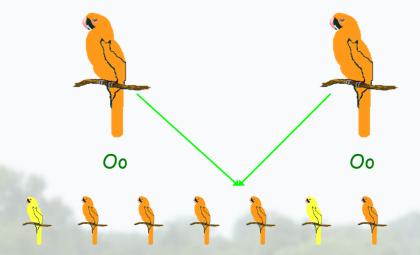


How to Determine Modes of Inheritance...

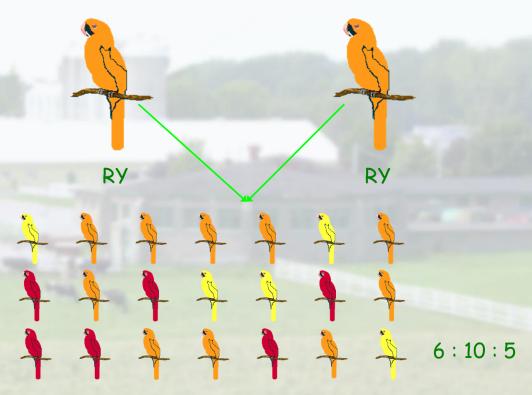


- Dominance/Recessiveness
- Codominance / Incomplete Dominance
 - 1:2:1 ratio
 - Both parents have the <u>same</u> phenotype and approximately 50% of the offspring have the same phenotype as the parents
- Multiple Alleles
 - Could <u>also</u> be 1:2:1 ratio <u>but</u> parents will have different phenotypes
- Lethal
 - Ratios will <u>not</u> add up to the number of expected combinations a 2:1 ratio is typical
- Epistatis
 - "Playing with the ratios" to get them to work!!
 - A "large" number of modified phenotypes → Dominant Epistasis; a "small" number of modified phenotypes → Recessive Epistasis
 - More than one "modification" → Codominant Epistasis
- Sex-influenced
 - You will have to be given numbers of males and females. The only case where one genotype can have 2 phenotypes.
 - Also, there ARE only two phenotypes!! IF there are 3 that means sex-linked
- Sex-linked
 - · You will have to be given numbers of males and females
 - The heterogametic (XY) sex cannot express the heterozygous condition
 - The heterogametic (XY) sex is Male in Mammals and Female in Birds.



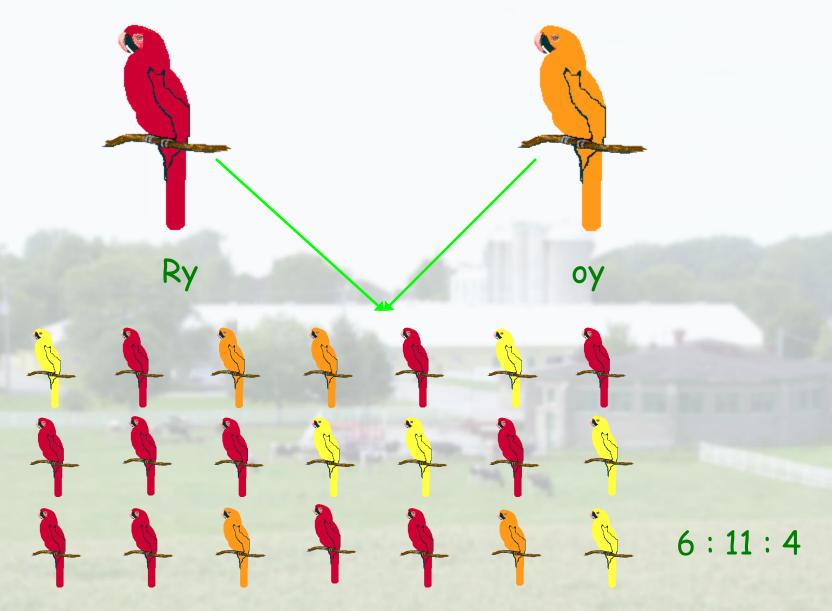


After 1 generation: Simple Dominant-Recessive Trait (or arguably a lethal with 2:1 ratio)

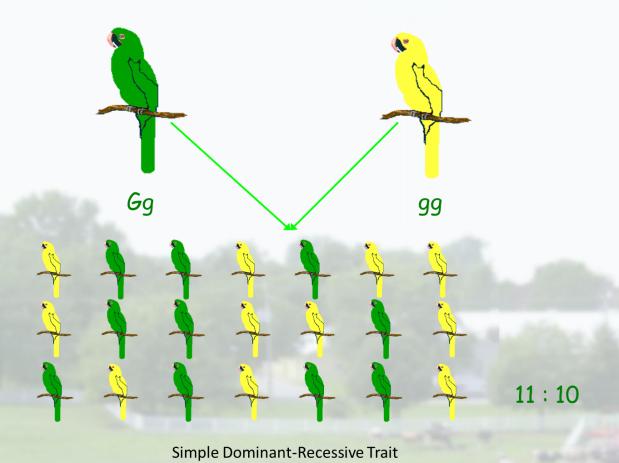


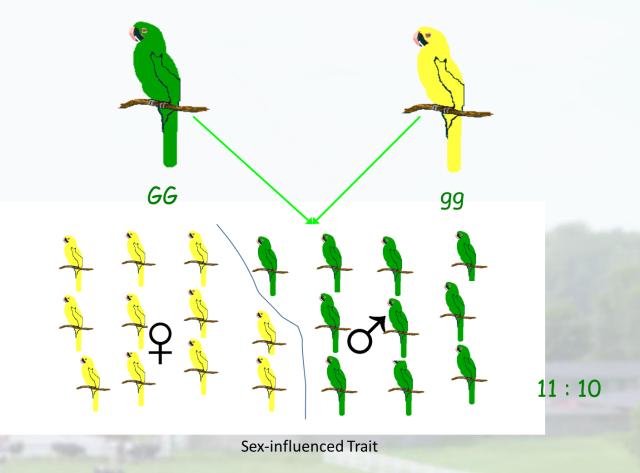
OVERALL: Incomplete Dominance / Codominant Trait



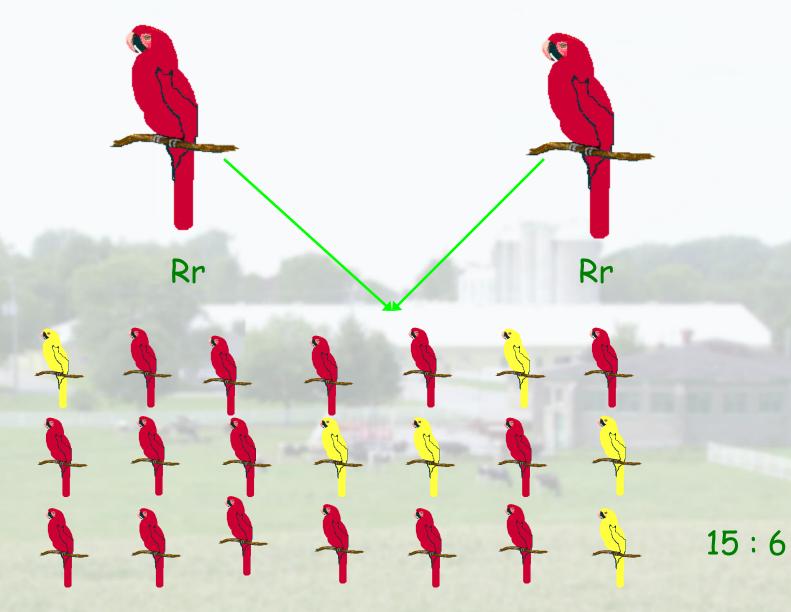














Simple Dominant-Recessive Trait