FERRETS

Volume Three

The Coat Colour Book

By Fret Popper

Contents

Chapter One

The Importance of Colour

The ferret is unique amongst all polecat species - it is the only one who lives amongst humans. Its habitat is not the forest or field, nor the river's edge or semi-desert, the ferret's habitat is a cage or living room, a showground or rabbit infested paddock. And more - the ferret is the only polecat species that sports a wide range of coat colours.

Polecats who live in deep forests are very dark in colour. Mum and Dad are nearly black and so are their Kits. Those who live in more open country and near human settlements tend to be lighter in colour. But not as light as the Steppe polecat who prefers to live in open grasslands and semi-deserts. The sandy colour of the Steppe polecat blends well into the loess and sandy soils of its habitats. The colour of a polecat's coat depends very much upon where it lives. Photo 1.1 shows an European polecat male of very dark colour.

Photo 1.1 **European polecat, male**, courtesy Thierry Lode, France.

Ferrets come in many different colours. Living amongst humans allowed the ferret to express a wide range of coat colours its wild relatives the polecats could not. Natural selection weeds out any colours in a wild species if it fails to offer a survival advantage. But selective breeding can encourage the widest range of coat colours possible and allowing colours to pass down from one generation to the next.

In the Wild Colour means Camouflage.
In the deep dark forest a dark coloured polecat has a better chance of not being seen by its prey or its predator and thus has a better chance to survive and have offspring of the same colour, whereas a black polecat in open grassland would quickly fall prey to a hunting raptor. Conversely a sandy coloured polecat in the dark deep forest would be highly visible to its prey and predator alike finding it hard to catch a meal, but be an easy meal itself.

Colour means Recognition.
Polecats and other wild animals are very choosy about who to mate with, as every zoo breeder of endangered wild animals knows. It may smell right but if it doesn't look 'right' they may give it a miss. For example, it could very well be that a black polecat who grew up amongst black polecats - every polecat it has ever seen was black - may not recognise an albino or sandy polecat as a potential mate. Or worse, a sibling of a different colour than the rest of the litter might be bullied by its littermates or even rejected by its mother. Being the odd one out is not a survival feature in the wild.

In Captivity Colour also means Pleasing Humans.
Breeders may outdo each other by producing animals of unusual coat colours or breed for certain colours people want. Once the Albino, the white ferret with pink eyes, was the preferred hunting companion. Recently, with the rise of the show and companion ferret any colour could become fashionable - for better or for worse.

Ferrets are not fussy about the colour of their mates. Their kind comes in many shades and patterns. They are used that. Mum and Dad of the same colour can have Kits of a range of colours. Life amongst humans not only eased the pressure of natural selection but also, by the practice of selective breeding, encouraged the proliferation of any coat colour or pattern that is genetically possible.

Lack of Colour may mean Health Problems
We are only too familiar with the effect of albinism on the visual system in any species. In many animals white-spotting especially about the head is related to deafness. Dalmatians with the most extensive white areas are often deaf.

Nervous excitable pigs are usually very pale or white. The pale Australian shepherds have a high incidence of brain, ear and eye problems.

Aleutian coloured mink have the dubious honour having a virus named after it, because mink of this particular grey colour are exceptionally susceptible to the Aleutian disease virus, ADV, a parvovirus that infects mink and ferrets.

What can I say other than - when you choose the colour of your coat - choose wisely!

Sources:

Wallin, M., *'Nature's palette'*, Department of Zoology, Goeteborg University, Sweden, 2002

Genetics and the Behaviour of Domestic Animals, T. Grandin (Editor), Academic Press, San Diego, California, pp 319-341(1998), with 1999 updates.

Chapter Two

The Four Ferrets of Mayhem …and More

The 'Wild-Type' Colour
The Albino
The 'Mitt' Pattern
The 'Dark Eyed White' Pattern
Other Colours and Patterns

To begin with I must say something about the confusing coat colour nomenclature. As much as possible I will avoid using the fancy terms so popular in show circles, because frequently different terms are used for the same colour or the same terms for different colours depending where you live and to which club you belong. But as soon as I started thinking 'black and white and shades between' my understanding of the subject improved considerably.

It's really quite simple. Pigment makes coat colour. If you have lots of pigment you have a dark coat, no pigment means your coat will be snow white after a good shampoo. And if you have some pigment your coat will be 'a shade in between'. It can also happen that pigment doesn't cover every part of your coat evenly but that doesn't mean you are a freak, you may be a 'Mitt' or 'Dark Eyed White' or a ferret with large white spots.

What's my Coat Colour?
The darkest pigment in your fur determines your coat colour. Ignore the lighter coloured patches in your coat and the colour of the undercoat. You find the darkest pigment in the guard hair or in the tip of the guard hair.

What is Pigment?
Pigment is pigment - doesn't matter what species you are - monkey, mouse or mustelid. The genes responsible for pigment production are the same in all mammals. Another term for pigment is *melanin.* It's a long and complicated chemical process by which the body makes melanin. If everything goes right we end up with two different types of melanin, one gives us the blacks and browns, and the other the reds and yellows. Ferrets in general have more black/brown pigment than red/yellow pigment. Yellow in ferrets is more often than not associated with 'body-grease' than with pigment.

Of course pigment just doesn't float around anywhere in the body. Pigment is produced in pigment cells. These cells are situated at the base of the hair roots. The pigment they produce is inserted into the growing hair. Skin may be pigmented too. Look at the black or spotted noses of some ferrets. Eyes have pigment as well except the eyes of the albino ferret.

The 'Wild-Type' Ferret

The ‘Wild Type’ Ferret’s coat colour resembles that of its wild relatives the polecats of Europe with dark extremities and the typical bandit mask. Other names for Wild Type Ferret are Fitch, Sable, Poley, Polecat Ferret, Polecat or Black Ferret.
Rosie is a fine example of this type of ferret. (See photo 2.1)

Photo 2.1, **Ferret Rosie Smith,** courtesy Geoff Smith, SA.

The Albino Ferret
The Albino Ferret lacks all pigment. Its coat is white, its eyes are pink, its eyesight is not the best. Albinos are not necessarily deaf - just hard of hearing at times. In the past, the Albino Ferret was selectively bred as the preferred hunting companion and the term *Ferret* became synonymous for *Albino*. (See photo 2.2) Albinos do have pigment cells but no pigment. More on this in chapter 10 ‘Understanding Albinism’.

Photo 2.2, **Albino Ferrets**, courtesy Geoff Smith, SA.

The ‘Mitt’ Ferret
In most cases the **Mitt ferret** is a Sable ferret with white markings on its paws, a white chest patch and white spots on its knees called blinkers.

Photo 2.3a, **Sable Mitt Ferret,** courtesy Ines Mey, Germany.

Photo 2.3b, **Brown Mitt Ferret,** courtesy Ines Mey, Germany.

Ferrets of any colour can have Mitt spots. It is a common coat colour pattern in otherwise pigmented ferrets. (See photos 2.3a and 2.3b) The white spots are caused by the lack of pigment producing cells. Paws, knees and chest are the last places that pigment cells migrate to in the embryo. A lack of pigment in these areas isn't necessarily inherited, but it is more likely that the pregnant Jill was exposed to minor adverse environmental influences during the critical stage of cell migration in the embryo. Pigment cells originate in the neural crest. From there they migrate to all parts of the body. It all depends on timing. The cells have to reach their destination within a precise time frame. Any slowing of this process, whatever the reason, results in white markings because the pigment cell couldn't get there in time.

Mitt is not '**Irish Spotting'** where the white areas are much larger sometimes covering the whole body of the animal. Irish Spotting is hereditary. Albinos can have Mitt spots even Irish Spotting, only you can't see them.

The 'Dark Eyed White' Ferret

'Dark Eyed White' or DEW, sometimes called 'Black Eyed White' or BEW, has white fur and coloured eyes. It comes in two different versions. The more common one is not completely white, because its fur is interspersed with pigmented guard hair, like 'pepper and salt' also called 'roan'. (See photo 2.4) The other version is a coloured ferret with a big white spot covering its whole body, as in *extreme* Irish Spotting.

Photo 2.4, **Ferret Herbie** is a typical 'pepper and salt' DEW, courtesy Geoff Smith, SA.

White at the Wrong Place

Badger Stripes - Blazes - Panda Markings

In ferrets these markings almost certainly carry a congenital defect, which shares some similarities to the Waardenburg syndrome in humans. Waardenburg like coat colour patterns not only cause these white face markings but also cranial deformation in the womb, which broadens and flattens the skull leading to partial or total deafness. And beyond that the cranial deformations also lead to a higher instance of stillborn kits.

Other Colours and Patterns

*Sandy, Cinnamon, Champagne, Butterscotch, Sterling, Silver, Chocolate, Points, Blaze, Siamese, Panda, Solid, Standard, Panda Champagne, Chocolate Mitt, Sandy Point, Black Self Mitt, Sable Fine Point, Chocolate Fine Point Mitt …**enough to make your head spin …*** are just a few of the popular terms you find in ferret books. But as I see it all those colours mentioned are the product of two types of pigment or their absence. That's all there is to it.

Chapter Three

A Crash Course in Genetics

To understand Coat Colour Genetics and Inheritance is not as difficult as it looks at first sight. All we need to know is what type of pigment is made, how it is distributed, and what happens when the body doesn't make pigment or doesn't make enough. It's also a good to know in what way Mum and Dad are responsible for the coat colour of their offspring. So, let's get started!

The basic questions of heredity are as ancient as civilization itself.

- ***Why is it that animal and plant species almost always produce offspring very similar to the parents?***
- ***Why is it that no exact copies are made, that there is always some variation?***

It all comes down to genes. Everybody is familiar with the term *'gene'* and we have thousands of them. Genes are sets of instructions for making proteins. Sexually reproducing organisms have two copies of each gene, called a 'gene pair' one copy from Mum and one from Dad. Each copy is called an *allele.* The two alleles of a gene pair don't have to be identical, often one is *dominant* the other *recessive.* It just means that the instructions you get from Mum are different to those you get from Dad. Here it becomes interesting because the different instructions make all the difference. They give ferrets the wide range of coat colours, from black to white and every shade between. Those different instructions are *mutations.*

For a Polecat coat colour inheritance is straightforward. Mum and Dad's coats are 'Wild Type' all their offspring will be 'Wild Type' too. Not that the odd variation pops up occasionally but this is usually quickly taken care of by natural selection.

But if you are a ferret the situation becomes a lot more interesting. Mum and Dad may be one colour, but their offspring could have one or more different coat colours. More often than not there will be a few Albino Kits amongst Sables. (From now on I will use the term 'Sable' instead of 'Wild Type' when I speak of ferret coat colours.) Other coat colours too can appear; selective breeding can encourage this. A good example is my own family. My Mum and Dad got different instructions for making pigment from their parents and passed them down to their kits, the result - a mixed bag of colours. Why?

My Mum Rebecca is Sable. She inherited this colour from her Sable Mum and not from her Dad, because her Dad is Albino. Rebecca has a working allele on the C locus making tyrosinase an enzyme essential for pigment production. But from her Dad she inherited a non-working allele on the same locus doing nothing. One working allele is sufficient for making pigment. With my Dad the situation is very much the same. His Mum is pigmented, his Dad is Albino. That makes both my parents carriers of the non-working albino allele. And I inherited two non-working albino alleles, one from Mum and one from Dad.

These days our Dad Papa Putorius has white fur. His is not an ‘albino white’ like mine, but ‘greying with age white‘. Greying with age is a phenomenon not uncommon amongst ferrets, horses and people. Papa Putorius is very old and still going strong. Therefore I’m quite sure he doesn’t have a mutation on the D-locus. Mutations on the D-locus not only produce fancy coat colours, like dilution greys or creams but also health problems for the individual. *(See chapter 18 ‘Coat Colour and Life Expectancy‘)*

I am Albino and so are my sisters Lucy and Tara. But my brothers Chan, Chips and Rokko are not, all three are pigmented, Chan is a dark Sable, Chips is a brown Sable and Rokko is a brown Mitt.

If all that sounds a little complicated, no fear, the Punnett Square will make it all clear.

Chapter Four

The Punnett Square

One of the easiest ways to calculate the mathematical probability of inheriting a specific coat colour, or any other trait, was invented by Reginald Punnett. His technique is what we call a **Punnett Square**.

The setting up and interpreting of a Punnett square is quite simple provided we know how to use it. Let's start with a very simple example involving the C locus. At this locus an albino ferret has two alleles for albinism labelled cc. **A fully coloured ferret has one of two possible combinations, either CC or Cc.** The capital letters represent the dominant alleles and the minor letters the recessive alleles.

From Mendelian Genetics we know that,

• Alternative versions of coat colour genes (alleles) account for variations in inherited coat colour.
• For each coat colour trait a ferret inherits two alleles, one from mum and one from dad.
• If the two alleles differ, then the dominant allele is expressed. The recessive allele has no noticeable effect on a ferret's coat colour.
• Reproductive cells - ova and sperm - have only one allele of each pair of alleles. At fertilisation alleles for traits 'recombine', producing the genotype for the traits of the offspring.

Unless you are familiar with the terms used in this chapter, such as genotype, phenotype, carrier, etc. go to chapter 6 *'Language of Inheritance'* for a quick reference.

1. Where both parents are albino:

		albino	
		cc	
albino	cc		
		c	c
	c	cc	cc
		albino	albino
	c	cc	cc
		albino	albino

Genetic contribution of one parent *cc* (albino)
Genetic contribution of the other parent *cc* (albino)
Offspring genotype possibilities *cc*
Offspring phenotype possibilities albino only.
Albino parents will **always** produce albino offspring - **albinos breed true**.

2. Where one parent is albino, the other is full colour but carries an albino allele:

		albino	
		cc	
sable	Cc		
		c	c
	C	Cc	Cc
		sable	sable
	c	cc	cc
		albino	albino

Genetic contribution of one parent *Cc* (full colour but carries an albino allele)
Genetic contribution of the other parent *cc* (albino)
Offspring genotype possibilities *Cc* and *cc*.
Offspring phenotype possibilities: Some full colours carrying albino, some albinos.

3. Where both parents have full colour, but each carries an albino allele:

		sable	
		Cc	
sable	Cc		
		C	c
	C	CC	Cc
		sable	sable
	c	Cc	cc
		sable	albino

Genetic contribution of one parent *Cc* (full colour but carries one albino allele)
Genetic contribution of the other parent *Cc* (full colour but carries one albino allele)
Offspring genotype possibilities *CC*, *Cc* and *cc*
Offspring phenotype possibilities: Full colours some carrying albino and some not, and some albinos.

4. Where both parents have full colour, without the albino allele:

		sable	
		CC	
sable	CC		
		C	C
	C	CC	CC
		sable	sable
	C	CC	CC
		sable	sable

Genetic contribution of one parent *CC* (full colour)
Genetic contribution of the other parent *CC* (full colour)
Offspring genotype possibilities *CC*.
Offspring phenotype possibilities full colour.

5. Where one parent has full colour without the albino allele, the other is albino:

		sable	
		CC	
albino	cc		
		C	C
	c	Cc	Cc
		sable	sable
	c	Cc	Cc
		sable	sable

Genetic contribution of one parent *CC* (full colour)
Genetic contribution of the other parent *cc* (albino)
Offspring genotype possibilities *Cc*, all carry an albino allele, but
Offspring phenotype possibilities full colour only.

Chapter Five

The Popper Family's Coat Colour Punnett Squares

My parents Rebecca and Papa Putorius fit the number 3 Punnett Square (See chapter 4) on the Albino locus. Both are coloured and both are carrying the Albino allele. The proof of their carrier status is their albino offspring - Lucy, Tara and Fret.

But what about my coloured brothers Chan, Chips and Rokko? All three inherited at least one fully functioning C- locus allele. Maybe even two, as the Punnett Square number 3 in chapter 4 shows.

That's not all. How come Chips is brown? *(See chapter 10 ALBINISM, subheading 'Brown')* Because Chips has inherited 2 recessive alleles on the B-locus - one from Mum and one from Dad, as the story goes. Rebecca although not showing the trait is obviously a carrier of brown and Papa Putorius in his youth sported a luxurious brown coat until the 'greying with age' factor kicked in which is explained in chapter 16.

Rebecca and Papa's Punnet Square for the B-locus -

		Papa P	
		bb	
Rebecca	Bb		
		b	b
	B	Bb	Bb
		sable	sable
	b	bb	bb
		brown	brown

Genetic contribution of one Parent *Bb* (full colour)
Genetic contribution of the other parent *bb* (brown)
Offspring genotype possibilities *Bb* or *bb*
Offspring phenotype possibilities sable and brown

Now to the next step of combining locus B and locus C Punnett Squares,

		Papa P			
		bbCc			
Rebecca	BbCc				
		bC	bC	bc	bc
	BC	BbCC	BbCC	BbCc	BbCc
		sable	sable	sable	sable
	Bc	BbCc	BbCc	Bbcc	Bbcc
		sable	sable	albino	albino
	bC	bbCC	bbCC	bbCc	bbcc
		brown	brown	brown	albino
	bc	bbCc	bbCc	bbcc	bbcc
		brown	brown	albino	albino

6 dark sable, 5 brown sable, 5 albino

From this Punnett Square it's easy to see that in my family the **mathematical probability** of inheriting the dark sable coat colour is almost 40%, for brown it is a little over 30% and for albino also a little over 30%.
In other words, 6 out of 16 dark sable, 5 out of 16 brown sable, 5 out of 16 albino.

We can also see the carrier status probabilities.
2 dark sable out of 6 sable are not carriers of the albino allele the other 4 are.
All 6 dark sable are carriers of the brown allele.
Two browns do not carry the albino allele the other 3 are carriers.
Interestingly 2 albinos have a working allele on the B locus the other three do not.
However we cannot tell who the carriers are by just looking at them only genetic testing can.

Other than that we can tell by the colour of the offspring of breeding pair whether or not one or the other is or maybe is not a carrier of a particular trait - provided we keep accurate records who mated with whom and what colours popped up!

Rebecca and Papa Putorius are a good example of discovering a carrier status. Rebecca didn't know she was a carrier of brown until Brown Chips was born. And we three albinos, Lucy Tara and Fret, confirmed their albino carrier status.

My Albino sister Lucy had many kits with Sasha a beautiful Sable hob. All their kits are Sable. It is unlikely that Sasha is a carrier of albino but we can never be 100% sure. Nor did they ever have brown kits. Which may mean that one or the other could be a carrier of brown, but not both, or that neither is a carrier of brown. We can only guess.

Chapter Six

The Language of Inheritance

For quick Reference

Genome is the complete set of genetic material for any cell.
DNA is the blueprint for the construction of every living entity. DNA is organised into dense packages called **chromosomes.**

Chromosome architecture is unique to every species; Thousands of genes are located on specialised structures called chromosomes. Ferrets have 20 pairs; humans have 23, cats 19, dogs 39 pairs of chromosomes. They play an important role in the **reproductive isolation** of species.

Epistasis refers to the interactions between genes but not between alleles of a gene. A gene is **epistatic** when it influences the phenotypic expression of another gene.

Wild-type the way an animal looks with the greatest frequency in a wild population.
Wild-type gene refers to the normal, as opposed to the mutant gene or allele.

Mutation is a change in a hereditary characteristic that produces a new trait, which can be inherited. Mutations create variety.

- **Loss-of-function-mutation** - a gene or allele is 'broken' its function reduced or annulled. Phenotypes associated with such mutations are usually recessive. (See chapter 10, 'Albinism')
- **Gain-of-function mutation -** a gene gains a new sometimes abnormal function. These mutations usually have dominant phenotypes. (See chapter 13, 'Melanism')

Melanin, the substance that gives colour to hair, is produced in cells, which derive from neural crest cells. These cells arise in the embryo from tissue that later becomes the spinal cord. They develop into nerve cells and **melanocytes.** Melanocytes are found in hair follicles where they add pigment to the hair as it grows. There are two biochemically distinct types of melanin - **eumelanin** and **phaeomelanin.** In their unmodified forms, eumelanin is black or dark brown and phaeomelanin is red or yellow. **'White' is not a pigment but the lack of pigment in an animal's hair**.

Dominate - Recessive - Carrier

Are the key terms for understanding inheritance.

*The Albino locus also called **C - locus** may be best to demonstrate 'dominant versus recessive' and what it means to be a carrier.*

We all know that the colour **Sable** is **dominant** and **Albino** is **recessive.** But why is it

that some traits are dominant and some are recessive? Why can Sables be carriers of Albino but why can't Albinos be carriers of Sable? Mating Albino to Albino will always produce Albino offspring, never a coloured one. There are exceptions but they are rare indeed as we will see later. Mating Colour to Colour can produce Albino kits provided both parents are carriers of Albino.

Carriers don't exhibit the trait themselves but two non-albinistic parents who are carriers of albinism are able to produce albinistic offspring.

It all depends on genes. A gene is just a set of instructions for making a protein. The simplest situation of dominant and recessive alleles is if one allele makes a working protein and its partner on the same locus makes a broken protein or no protein at all. When this happens, the working protein is usually dominant. The broken protein doesn't do anything, so the working protein wins out.

In the case of Sable versus Albino the protein involved is an enzyme called tyrosinase, which is essential for the long process of turning tyrosine into pigment.

As long as you have one working gene on the Albino locus, you won't be Albino. With one working gene and one non-working gene on the Albino locus the working protein picks up the slack. But if both genes on the Albino locus are non-working, you will be Albino not matter what other colour gene you have. This is a good example of **Epistasis**, the masking of the effects of genes by the action of others.

But it may also be the case that none of the alleles on the C - locus are working to full capacity. When this happens a wide range of coat colour shades can be expressed. As explained in chapter 10 about Albinism.

Genotype versus *Phenotype*

A ferret's colour **phenotype** is what you see. A ferret's colour **genotype** refers to the genes that contribute to his or her colour. Genes that control pigmentation of mammalian pelage interact with each other in intricate networks.

The genotype is the genetic code responsible for what we see. In some cases, there may be more than one gene code that gives the same appearance.

Think of it like in maths, if the answer is 6 there can be different formulas to get to the same answer, 3+3 or 2+4 or 1+5 or 1+2+3 or 8-2, and so on.

For decades that complex process has been studied using mouse coat colour mutations leading to the realisation that homologous genes in other species determine common phenotypic variations including albinism, erythrism (red hair or fur) piebaldism and many more.

Locus - Gene - Allele

Locus is a space on a chromosome occupied by a particular **gene.** Each locus is

occupied by two genes or alleles, one inherited from the mother and one from the father. Each gene can occur in more than one form. These variant forms of a gene are called **alleles.** Alleles arise spontaneously in nature as a result of a mutation of the **wild type gene.** The wild type gene is usually, but not always, **dominant** suppressing the effects of the mutant or **recessive** allele.

Homozygous versus *Heterozygous*

When an individual has two **identical genes** at a locus, it is said to be **homozygous.** Individuals with **different genes** at a locus are **heterozygous**. Homozygous pairs of genes can be either dominant (CC) or recessive (cc). Heterozygous pairs are made up of one dominant and one recessive allele (Cc).

Gene Identification

Genes and their alleles are usually identified by letters:

- **A** stands for agouti**,**
- **B** stands for black or brown,
- **C** is the albino locus that determines pigmentation or lack thereof, dilution or
- **D** stands for dilution and determines the intensity of pigmentation,
- **E** or extension locus is of interest to all with red hair or fur,
- **G** for greying with age,
- **P** is ‘pink-eyed-dilution‘,
- **S** refers to ‘Irish spotting‘.

Capital letters represent dominant genes and lower case letters, recessive genes.

Germ Cell versus *Somatic Cell*

Germ cells are the reproductive cells and include the egg and sperm cells. Egg cells are formed in the ovaries of the female; sperm cells are formed in the testes of the male by a process called **meiosis**. Germ cells are notable for containing only half the amount of DNA. They have a single set of chromosomes of 20 in ferrets (humans 23, dogs 39). During fertilisation egg cell and sperm cell fuse to produce a cell called a zygote, from which the entire mammalian embryo develops.

With few exceptions every other cell type in the mammalian body is a **somatic cell.** Somatic cells contain two sets of chromosomes, one from each parent, that is the complete amount of DNA and all the genetic information necessary to form a new being, be it human, ferret, mouse or any other creature. Every internal organ, skin, bones, blood, and connective tissue are all made up of somatic cells. Somatic cells divide by a process called **Mitosis.**
The word "somatic" is derived from the Greek word *soma* meaning "body".

Cell Divisions
Mitosis versus *Meiosis*

Mitosis - The process of division of somatic cells in which each daughter cell receives the same amount of DNA as the parent cell.
Meiosis A special form of cell division to reduce the chromosomes within it to half the normal number. This is to ensure that fertilisation - the joining of the male gamete (sperm) and the female gamete (egg) - restores the full number of chromosomes rather than causing an abnormal number of chromosomes.

Chapter Seven

A Gene is a Gene is a Gene

Be they in a fly, a worm, a mouse, a plant, a ferret or a human the functions of many genes are fundamentally the same. Genes have been conserved over geological time to meet the needs of millions of species. We know what happens in one species, e.g. humans, because the same happens in mice, or fruit fly or whatever species model is the most homologous for the trait of interest. As far as skin and coat colour is concerned the functions of the pigment genes are essentially the same amongst mammals. Coat colour in ferrets, as in all mammals, is the result of 'colour genes' working in concert to give us the spectrum of colours we see in the real world.

Essentially coat colour is the result of two processes. One is the ability of pigment cells to produce pigment and the other process takes care of the distribution of pigment cells in hair, skin and eyes. Pigment or melanin is the end product of a long chain of biochemical reactions in the pigment producing cells called melanocytes, commencing with the amino acid **tyrosine.**

Genes producing pigment - Genes modifying pigment - Genes distributing pigment - Genes controlling pigment cells and their distribution. There are well over hundred such genes but the ones of interest to us are the following:

Locus A: Determines the amount and the localisation of dark and light pigment, both for the individual strands of hair and for the fur as a whole. It is the 'Agouti Factor'. *(See chapter 8 'The Agouti Factor')*

Locus B: Determines whether the colour will be black or brown. *(See chapter 10 'ALBINISM' subheading 'Brown')*

Locus C: Determines the production of pigment, the amount or the lack thereof. It is also called the chinchilla locus it's numerous alleles give rise to many variations in the depth of the pigmentation or no pigmentation, from Sable to Albino and many shades between. *(See chapter 10 'ALBINISM' subheading 'Albinism')*

Locus D: Determines the intensity of the colour - Black to Silver Grey and 'Blue' or Brown to Cream. *(See chapter 15 'Dilution')*

Locus E: Some alleles give us 'Red-Heads' others solid Blacks. *(See chapter 12 'Redheads' or Erythrism' and chapter 13 'Melanism - Black Ferrets?')*

Locus G: alleles in this locus determine whether or not the colour fades with age - 'greying with age' provided you are a **horse**. (See chapter 16 'Greying with Age')

Locus P: influences the production of Black and Brown pigment but not Red or

Yellow pigment. *(See chapter 10 'ALBINISM' subheading 'Pink-Eyed-Dilution'*)

Locus S: determines whether or not the coat has white markings called Irish Spotting. The dominant allele S gives a uniform pigmentation, though occasionally with white spots on the feet and chest. The three recessive s-alleles give varying amounts of white spots; sometimes the animal is mostly white. *(See chapter 9 'Whites')*

Source:

Jackson, I., *Homologous pigmentation mutations in human, mouse and other model organisms'*, Oxford Journals - Human molecular Genetics, 1997, vol. No.10, pp. 1613-1624. http://hmg.oxfordjournals.org/cgi/content/full/6/10/1613

Chapter Eight

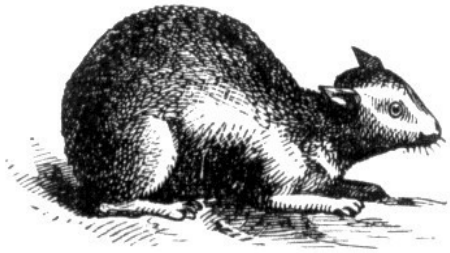
The Agouti Factor

The Agouti gene encodes for a protein in specialised cells at the roots of the hair that causes the melanocytes, the pigment producing cells, to switch from making one colour or the other or sometimes no colour at all.

All Sable ferrets - black or brown - have banded guard hair. Look at a single hair with a magnifying glass and what you see is not a uniform brown or black hair from tip to base but more likely a hair with a dark tip, somewhat lighter in the middle part and nearly white at the base. This banding is called Agouti after the South American rodent Agouti with colourful-banded hair. Agouti simply means a coat colour type that has stripes or banding on an individual hair.

Agouti

The word 'agouti' takes its name from a native South American language, where it refers to the rodent 'Golden Agouti' *Dasyprocta aguti.* Within Genetics, however, agouti describes the coat colour gene responsible for the 'wild type' in mice and other mammals. Agouti acts in the hair follicles, primarily affecting the relative amount and distribution of yellow pigment and black pigment. An individual hair has black pigment at the tip and the base, and a band of yellow pigment in the middle**.**



Agouti

The Agouti Locus or* A-Locus

The product of the **agouti** locus is the **agouti signal protein** or **ASIP.** ASIP (synonyms: agouti, agouti signal protein, As, ASP) blocks the **melanocortin 1 receptor** (**MC1R**) on the melanocytes and prevents **melanocyte-stimulating hormones (MSH)** from binding to them. When ASIP is present, melanocytes produce phaeomelanin causing the banding effect on hair by a sudden switch from the production of eumelanin to phaeomelanin. The result is a hair with a dark, eumelanin-containing tip and light phaeomelanin middle. The base of the hair is often without pigment. (See photo 8.1, banded guard hair). This colouration softens the visual outline of an animal in the wild making it harder to see than a solid coloured animal.

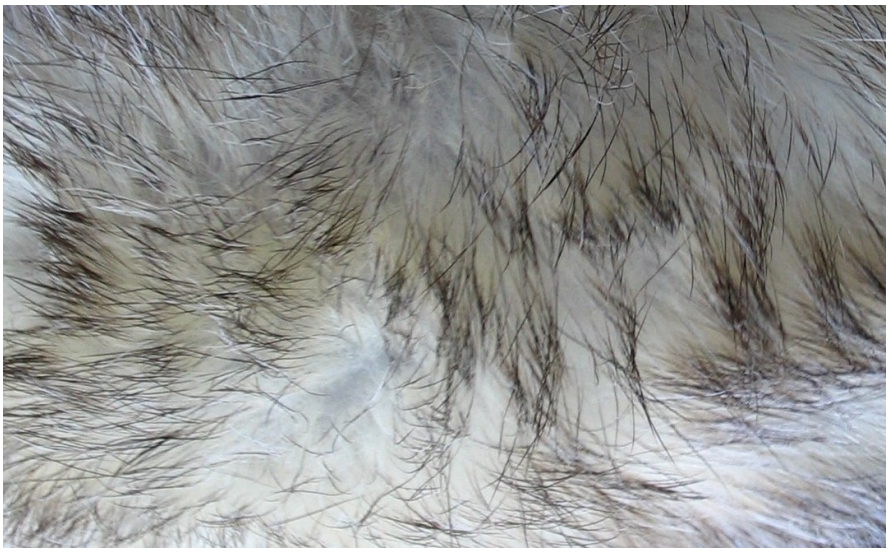


Photo 8.1 **Agouti ferret fur**, courtesy K. Bernhard, Tasmania

Agouti is the typical coat colour found in wild animals helping them to blend into the background. Concealment is important for prey and predator alike. Small predators need to avoid lager predators while at the same time remain undetected by its own prey.

Within genetics the term Agouti describes the gene responsible for a phenotype where most hairs in the fur have black or brown tips with bands of red or yellow towards the base.

Pigment cells produce pigment. Those in the skin inject pigment, usually the black or dark brown version, into the dividing cells of the skin. In ferrets this leads to dark skin on the nose. Other pigment cells move into the hair bulbs. These pigment cells inject their pigment into the growing hair shaft. They produce most pigment as the tip of the new hair is being formed. This is why the skin appears suddenly very dark some time after shaving for an operation that can be alarming the ferret owner. But this is just the sign that the regrowth of fur is underway. What you see is nothing else but the pigment rich tips of the hair just under the skin. Once the hair is above the skin the colour in that part of the hair is fixed.

Agouti inheritance

- ***A - Agouti, dominant (wild-colour, wild-type, sable, ticked)***
- ***a - non-agouti, recessive (solid colour, 'self')***

Therefore A/A and A/a will produce the Agouti coat colour, whereas a/a will produce a solid coat colour without banded hair. Solid coat colours are not rare in domesticated animal species but whether or not there are ferrets with such coat colours I cannot say. If there are they are rare, indeed. Of course the Albino is an exception it has no pigment at all for Agouti expression.

Animals with a gain of function allele E+ at the extension locus are solid dark independent of the alleles at the Agouti locus. Recessive homozygous at the extension locus lead to a complete extension of phaeomelanin and therefore to a red/yellow coat colour. A distinct differentiation between the effects of the Extension locus and the Agouti locus is not easy because both give rise to the same phenotypes. (See chapter 12 *'Redheads' or Erythrism'* 13, and chapter '*Melanism - Black Ferrets'*)

*** The functions of the *Agouti Locus or* A-Locus and *The Extension Locus* MC1R *or* E-Locus are closely interlinked and have been thoroughly documented in mice but not in ferrets or humans.**

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Chapter Nine

Whites

Pure white animals have always been popular. But many people find the pink eyes of the albino ferret somewhat spooky, thus the preference for whites with dark eyes. Breeding healthy albino ferrets is quite easy but breeding healthy white ferrets with dark eyes is much more difficult. Nevertheless these beautiful white ferrets with shiny dark eyes have captured the hearts of many ferret people. (See photos 9.1 and 9.2)

Unfortunately there are no references to be found in the literature on how to successfully breed healthy white ferrets with dark eyes. I say successfully, because 'white' can come with serious health problems. The albino ferret, apart from its poor vision, is usually a robust and healthy ferret.

Photo 9.1 **Albino ferret**
Courtesy Geoff Smith, SA**.**

Photo 9.2 **Dark eyed white ferret,**
Courtesy Geoff Smith, SA**.**

The Basis of White Coat Colour
White coat colour in mammals can be brought about in three ways:

- The complete absence of pigment granules as in Albinos. The albino mutation is a complete loss-of-function for tyrosinase, affecting the entire animal including the retinal pigment.
- The lack of pigment cells as in Dark-Eyed-Whites or Irish Spotting or Overo. White-spotting mutations tend to produce an irregular pattern in animals within the same species. In extreme cases the white-spotting mutation causes a complete white coat but with the retention of retinal pigment. (See chapter 11,*'Dark-Eyed-White')*
- By genes switching pigment production in melanocytes on or off. In polar bears it is permanently switched off, in snow hares and ermines and others who don a white winter coat it is seasonal switch, and in badgers, mink, zebras and many other wild animals those 'switching genes' produce a species specific and

consistent coat colour pattern. But whatever the underlying process this genetic variation in coat colour genes provided the means for environmental adaptation and selective advantage in some species during mammalian evolution.

Albinos have pigment cells but no tyrosinase to initiate pigment production from tyrosine. Dark Eyed Whites have tyrosinase for synthesising pigment but have no pigment cells. To use an analogy; Albinos have a cooking pot but no ingredients; Dark-Eyed-Whites have the ingredients but no pot for cooking. In both cases he cooks stand around with nothing to do. But Polar bears, snow hares, badgers, mink, and the rest, have the ingredients and the cocking pots but their cooks take leave on a regular basis.

The Pigment Cell Pathway

Melanocytes or pigment cells derive from neural crest cells in the early stages of embryonic development and are responsible for colour distribution on an animal. Neural crest cells, in turn, derive from tissue what later becomes the spinal cord and develop into pigment and nerve cells that colonise the body. Pigment cells don't always reach the most remote regions of the body. The lower limbs, chest, belly and under the chin may remain un-colonised and therefore white. This is the most common cause of white markings in many animal species such as cats, mice, horses, cattle, and dogs and, of course, ferrets.

When Things go Wrong
Pigment cells, but not pigment, are essential for the proper function of the inner ear. White spotting-mutations affecting the head region as in Waardenburg-syndrome may also cause deafness.

Not only pigment cell derive from neural crest cells but also nerve cells. Both share common pathways, consequently, mutation in some of the genes that affect coat colour affect other functions as well, such as neurological functions, immunological functions, fertility, and even appetite. Mutations on **endothelin receptor type B (Ednrb)**, **Kit oncogene (Kit)** and **Kit ligand (Kitl)** genes are responsible for white areas where pigment cells are either absent or greatly diminished.

Ednrb - endothelin receptor type B
Synonyms: ET-B, ETb, Sox10m1.
Several different alleles of this gene bring about different levels and distributions of white. The dominant allele produces essentially a normal coloured coat. A mutant allele often referred to as **'Irish spotting'** in dogs, typically produces white markings on the face, neck, chest and lower limbs. The so-called '**piebald spotting'** allele produces a wider distribution of white. And finally, the **'extreme white spotting'** allele is responsible for an almost entirely white coat. Thus, an animal of this genotype is really a coloured one with a big white patch. Animals exhibiting extensive white spotting are more likely to suffer from deafness than non-white animals. But Ednrb is also essential to the proper development of the enteric nervous system. Mutations of this gene are responsible for a variety of conditions in humans and animals. Human homologs of these loci are mutated in Waardenburg-Shah syndrome and in

Hirschsprung's disease in both of which pigmentary defects are also associated with megacolon. In the horse a mutation in EDNRB is the cause of the **Overo** pattern of white spotting. In the homozygote the foal is completely white and lacking nerve cells to the gut region, which causes it to die.

Kit & Kitl
Synonyms of Kit: belly-spot, Bs, c-KIT, CD117, Dominant white spotting, Fdc, Steel Factor Receptor, Tr-kit
Synonyms of Kitl: Gb, grizzle-belly, Mgf, SF, Sl, SLF, Steel, Steel factor, stem cell factor.

The Kit & Kitl gene are important to at least three migratory stem cell populations: the neural crest-derived pigment cells, the haematopoietic (blood forming) stem cells and primordial germ cells (initial sexual reproductive cell).

Mutations on the Kit locus occur frequently. In the mouse they cause reduced pigmentation, macrocytic anaemia (abnormally large blood cells) and sterility. Homozygotes or compounds of two different mutations are usually **Black-Eyed-White**, sterile, and have severe macrocytic anaemia, often causing death in utero or neonatal. Heterozygotes with wild-type have some white spotting with or without lightly diluted pigmentation; they are fertile, and they may be slightly anaemic.

The Dark-Eyed-White Albino

A Dark Eyed White albino? Of course it is possible, however it would be wrongly identified as just another albino, since its white markings are invisible in an albino phenotype. It's a ferret without pigment and without pigment cells including all possible health problems associated with the Dark-Eyed White-phenotype.

BEWARE OF TOO MUCH WHITE

Dog breeders know, horse and cat breeders know, the same goes for pig and cattle breeders, and it has been proven in laboratory mice that certain genotypes that produce a white or almost white phenotype (albino excluded) are also responsible for a variety of undesirable conditions, like deafness, nervous system disorders, infertility, blood disorders, intestinal problems, reduced litter size due to prenatal and postnatal deaths. To breed white to white is fraught with failures. Why should it be any different in ferrets?

Mutants are natural variations, which occur due to spontaneous genetic changes or the expression of recessive genes. Recessive genes show up when there is too much inbreeding. White animals are uncommon in the wild as they lack normal camouflage. Polar bears are one exception. Some animals go with the seasons and put on a white coat for camouflage in the northern winter. Others have white markings, which are consistent in the location from animal to animal within a species, white tails on deer and rabbits, white stripes on zebras, chest patches on mink, white face markings on wolves and warning white bands on skunks. However

these markings serve a purpose - communication, breaking up the animal's outline, or warning potential predators. The variable white blazes, stockings, chest patches, collars, tail tips and mitts we see in some breeds of almost every domesticated mammal are extremely rare in wild animals but may persist in feral populations.

Sources:

Barsh, G.S., '*Coat Color Mutations, Animals'* Academic Press, 2001
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School of Medicine, Beckman Center, Stanford,
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Chapter 10

ALBINISM

Albinism comes in many hues and shades - as there are many types of albinism. But something all types of albinism have in common - mutations on the pigment production genes inhibiting the full expression of other coat colour genes. All ferrets, regardless of genotype, lack pigment in the presence of c/c but still possess a full complement of normal pigment cells. The inability of albino animals to produce pigment stems from a lack of tyrosinase and not the absence of pigment cells like it is the case in 'white spotting'.

Let's examine the more common mutations, which give us a wide range of coat colours in many species not just ferrets. Colours like the many shades of grey and brown, the Siamese and of course the ubiquitous albino ferret.

Albino

***Oculocutaneous albinism type 1* - OCA1**

'Pink-Eyed-Whites' - Siamese - Greys

- ***C = full colour - dominant***
- ***cch = grey (chinchilla) - recessive to C - dominant to ch, ce, and c***
- ***ch = Himalayan (Siamese) - recessive to C and cch - dominant to ce and c***
- ***ce = extreme dilution - recessive to C, cch and ch - dominant to c***
- ***c = albino (pink-eyed-white) recessive to C, cch, ch and ce***

C-Locus
Synonyms: Chinchilla, Albino or Tyrosinase Locus

The product of the C-locus is **tyrosinase** the most important enzyme involved in melanin production. Tyrosinase initiates the conversion process of the protein **tyrosine** to melanin and allows the full expression of other colour genes. No tyrosinase means no colour even in the presence of all the other colour genes. This locus has numerous mutant alleles responsible for a variety of coat colours - the best known is the cc genotype or Albino, but there are others. Albino mutations affect the amount of tyrosinase and of melanin in pigment cells, but do not interfere with the production of pigment cells (melanocytes) themselves.

Oculocutaneous albinism type 1 **- OCA1** is a disorder that results from mutations to the tyrosinase gene. Several different types of mutations to the tyrosinase gene are responsible for producing two types of **OCA 1,** these are: **OCA 1A** type and **OCA 1B** type. Mutations can result in either inactive/no tyrosine (null mutations) or in the production of tyrosine enzyme that has reduced activity from normal (leaky mutations). Null mutations produce OCA 1A, leaky mutations result in OCA 1B.

All mutant alleles on the C-locus are recessive to wild type in phenotype, but heterozygotes with wild type may produce intermediate amounts of tyrosinase.

The development of pigment and therefore the intensity of melanin production in the coat hair is affected by the **Albino** or **C Gene**. The dominant form 'C' is referred to as 'full colour'. For the record, the Jackson Laboratory lists no fewer than 104 phenotypic lower series alleles on the C locus in mice. I will contend with four. In order of **decreasing dominance** they are:

- **Chinchilla** is a subtype of the OCA 1B mutation. It lightens most coat colours to **grey**. Phaeomelanin is greatly reduced but eumelanin only slightly. Eyes are black. Chinchilla is recessive to full colour but dominant to Extreme dilution, Himalayan and Albino. Chinchilla mutations in ferrets are called 'Pearl' in some European countries.
- **Extreme dilution** is a subtype of the OCA 1B mutation. The hair is very light grey and eyes are dark. Extreme dilution is recessive to full colour and chinchilla but dominant to Himalayan and Albino.
- **Himalayan** is subtype of the OCA 1B mutation and is exemplified by the **Siamese** cat but occurs in others species as well. In humans it is known as **temperature-sensitive albinism.** . The Himalayan mutation produces a heat sensitive tyrosinase, which does not produce melanin at regular body temperature but functions normally in cooler areas of the body. Hence, legs, face, ears and tail are usually dark, while the trunk of the animal remains almost white. The Himalayan mutation is recessive to full colour, chinchilla and extreme dilution but dominant to albino. This mutation also affects the eyes. Are there Himalayan ferrets? There are Himalayan mice, rabbits, hamsters, mink, cats, and humans; there may well be Himalayan ferrets. If kept outdoors in temperate climate the Himalayan ferret would grow a dark coloured winter coat and a lighter coloured summer coat; just like a Siamese cat.
- **Pink-Eyed-White -** OCA 1A - is the most severe form of albinism. A very old mutant it was already known in Greek and Roman times. Hair and eyes are completely devoid of pigment. The fur is white eyes are pink. Albino is recessive to all mutations mentioned above. Eyes are affected.

Although within a species there is a range of alleles on the C-locus - new fewer than 104 in mice - but any individual animal, even a mouse, can only have two alleles on the C-locus, for example;
full-colour/full-colour **or** *chinchilla/Himalayan* **or** *extreme dilution/albino* **or** *albino/albino,* etc.
One individual can never have three or more alleles on the same locus, for example: *Full-colour/chinchilla/Himalayan/albino.*

There is more to Albinism than what meets the Eye -
Albinism is in the Eye.

Albinism occurs across the animal kingdom, from whales to snails and insects, and in the plant kingdom. In the animal kingdom more than 60 different types of albinism have been identified. The term albinism refers to a group of inherited conditions and includes a wide range of characteristics arising from problems with pigment production or distribution.

The pigment concerned is melanin. As in animals, albinism in plants is caused by lack of pigment. But in plants the lack is fatal because the missing pigment is chlorophyll. Without chlorophyll, the albino plant has no way to manufacture the food needed for survival. Some plants have a reduced amount of the green pigment chlorophyll. These variegated plants survive but grow less vigorously than their normal green counterparts.

Not all white animals are albino
Polar bears are not a species of albino bears, nor are snow hares and other animals that don a white coat during the northern winter. Yet, there will be albinos amongst them. The difference is in the eyes not necessarily in the fur.

What are the problems with Albinism?
In one sentence - **albinisms means impaired vision, lack of camouflage and very fair skin**. Thus it should come as no surprise that albinism is rare in the wild animal population where vision and colouration is strongly linked to survival.

Melanin - what is it?
Melanin is the dark compound of the skin, hair, eyes, the substantia nigra of the brain and various tumours. Melanin contains carbon, hydrogen, nitrogen, oxygen, and often sulphur. Melanin comes in two forms - the dark brown and black **eumelanin** and the light reddish tan and blonde **phaeomelanin.**

Melanin - where does it come from?
Melanin forms in cells called **melanocytes.** These cells are found in the skin, in hair follicles, and in the iris and retina of the eye. A complex chain of chemical reactions converts the amino acid **tyrosine** to melanin pigment. A critical factor in this process is an enzyme called **tyrosinase.** If this enzyme is not present melanin cannot be made.

Genes inherited from both parents of an individual control pigment production.

Albinism arises from the combination of recessive genes that prevent the body from making the usual amount of melanin pigment.

Many alterations of certain genes have been scientifically proven to be associated with albinism and every alteration leads to a change in the complex processes involved in the production and distribution of melanin.

For example, white ferrets with pink eyes (***Oculocutaneous albinism type 1)*** inherit an 'albinism gene' from both parents. However, a ferret that inherits one albinism gene (recessive) from one parent and one normal gene (dominant) from the other parent will show no outward signs of albinism. Still, that ferret will be a carrier and can pass that gene to its offspring.

Unlike in most species, albinism is common in the ferret population. Thus the incidence of carriers ought to be equally common, as a direct consequence of the preference for albinos over centuries. Incidentally, the Macquarie dictionary defines 'ferret' as a domesticated, albinistic, red-eyed form of the polecat, used for hunting rabbits and rats in their burrows. There may be few ferrets, indeed, which are not carriers of albinism.

Melanin in the eye

Many abnormalities occur in the visual pathways of albinos. One major abnormality of the eye in albinism involves lack of development of a small but very important area of the retina called the fovea responsible for sharp vision. For unknown reasons the fovea does not develop in albinism. But the major problem of the eye in albinism involves the optic nerve connecting the retina to the brain. In the retina are the nerve cells that transmit the light signal via the optic nerve fibres to the vision area of the brain. From the normal eye nerve fibres go to both sides of the brain. Thus the left eye sends signals to the left and right side of the brain and the right eye does likewise. But in albinism the nerves from the back of the eye to the brain are misrouted and most signals from one eye go to the other side of the brain. This unusual signal pattern prevents the eyes from working efficiently together resulting in reduced binocular depth perception or three-dimensional perception.

To a lesser extent this 'albino vision abnormality' can manifest itself in coloured ferrets as well. I don't think anyone can tell how many ferrets are thus affected. But popular wisdom has it that ferrets don't see very well - maybe most ferrets are albino. Albinos come in many colours.

In the struggle for existence, albinos of any species, plant or animal, are at a disadvantage. Nature eliminates the less well adapted. But human fascination with the unusual protects and perpetuates these oddities of nature. Only under the care of humans is the survival of the Albino assured.

Pink-Eyed-Dilution

***Oculocutaneous albinism type 2* - OCA2**

- ***P = normal pigmentation - dominant***
- ***p = pink-eyed-dilution - recessive***

What is pink-eyed-dilution?
Pink eye dilution is a mutation on the p-locus. The dominant gene *P* produces full pigmentation of both the hair and eyes. The recessive *p* inhibits the production of eumelanin.

Mammals, and that includes ferrets, normally produce two types of pigment that are chemically different. The black/brown pigment is called eumelanin and the yellow/red pigment is called phaeomelanin. As mentioned earlier the chemical pathway of pigment production is a long and complex one and a thing or two might go wrong along the way. If everything goes well the animal will have what is called the 'wild type' coat colour. Wild type coat colour in ferrets is usually described as **'sable'.** But when things go wrong the results are coat colours other than wild type. The oldest and best known mutation in ferrets is **'albinism'.** An albino ferret is lacking both types of pigment, eumelanin as well as phaeomelanin. Albinos end up with a white coat and eyes that appear pink due to iris transillumination, that is, reflection of the blood vessels of the interior of the eye.
.
In 'pink eye dilution', or *p/p,* something goes wrong with the production of eumelanin leaving phaeomelanin production mostly intact. I know it is confusing but the brown hue in pink eye dilution is not 'eumelanin brown' it is 'phaeomelanin brown' - not a *black/brown brown* but a *yellow/red brown*, in show circles called 'champagne', others call it pale brown or beige. Champagne is a popular coat colour name in other species, too, including birds. Though the animals are of similar colour their genetic formula to produce this colour may be quite different.

Whether or not the ferret is *p/p* can be established by looking into its eyes. The irises will be coloured but there is none or very little pigment in the interior of the eye, maybe except for traces of pigment in the retina.

Pigment cells in the iris make both pigments, eumelanin and phaeomelanin. But the layers of pigment cell inside the eye almost exclusively make eumelanin. Pink-eyed-dilution eyes appear to be a darker than albino eyes and are sometimes referred to as 'ruby'.

In bright daylight when pupils are contracted the colour of the iris is visible, in not so bright artificial light the pupils are dilated showing the reflection of the blood vessels of the interior of the eye.

Why no eumelanin in pink-eye-dilution?
Pigment or melanin is made in pigment cells called melanocytes. Melanocytes are found at the base of each hair, in the skin and of course in the eye. In each melanocyte are tiny vesicles called melanosomes the actual factories of pigment production. There

are two types of melanosomes, phaeomelanosomes make phaeomelanin, and eumelanosomes make euemelanin. Both types of pigments have the same basic ingredients, the enzyme tyrosinase and the amino acid tyrosine. However, for the synthesis of eumelanin an acidic environment in melanosomes is required. The p-locus codes for a protein that regulates the pH of melanosomes but the pink-eye-dilution mutation inhibits the production of this protein. Consequently the pH in melanosomes becomes less acid, almost neutral and therefore unsuitable for eumelanin production. Phaeomelanin is not thus affected. The net result is a reduction in the dark pigments and a ferret with a pale coat and pink eyes.

Pink-eyed-dilution and inheritance
Pink-eyed-dilution is a recessive trait that means the ferret must inherit the pink-eyed-dilution mutation from both parents. The parents themselves may have almost any coat colour, not necessarily pink-eyed-dilution; however, each must be a pink-eyed-dilution carrier.

Sometimes a pink-eyed-dilution ferret may be mistaken for a true albino. This can happen when coat colour of pink-eyed is further diluted by another mutation. One such mutation occurs on the d-locus and is called 'dilution'. *D* normal pigmentation, *d* dilutes any pigment present. There may be other mutations to the same effect. The *diluted pink-eyed-dilution ferret* may be almost indistinguishable in phenotype from the albino ferret but its genetic formula is quite different. If two albinos parents produce a coloured kit or more, and you are sure there was no 'mistake', than one parent is *albino* and the other a *diluted pink-eyed-dilution*. And if you look very closely you might find that one parent is not as white as the other. Because the pink-eyed-dilution parent will always have traces of pigment in its hair somewhere, whereas the true albino ferret has none.

Please note: 'ped' or 'p-e-d' stands for 'pink-eyed-dilution' in the Punnett squares.

Mating an **albino** ferret (genotype **cc/PP**) to a '**pink-eyed-dilution'** ferret (genotype **CC/pp**) will result in **fully coloured offspring**. But each kit will carry the recessive albino, and pink-eyed-dilution genes (alleles).

		albino
		cc/PP
pink-eyed		
dilution	CC/pp	
		cP
	Cp	Cc/Pp
		sable

Mating an **albino** ferret carrying 'pink-eyed dilution' (genotype **cc/Pp**) to '**pink-eyed-dilution'** ferret carrying albino (genotype **Cc/pp**) can result in a mixed litter, albinos, sables, and 'pink-eye-dilution'.

		albino	
		cc/Pp	
pink-eyed			
dilution	Cc/pp		
		cP	cp
	Cp	Cc/Pp	Cc/pp
		sable	ped
	cp	cc/Pp	cc/pp
		albino	albino

Mating **two sable ferrets** each carrying albino and 'pink-eyed-dilution' **(**genotypes **Cc/Pp)** will also result in a mixed litter but with the likelihood of more sable but fewer albino ferrets.

		sable			
		Cc/Pp			
sable	Cc/Pp				
		CP	Cp	cP	cp
	CP	CC/PP	CC/Pp	Cc/PP	Cc/Pp
		sable	sable	sable	sable
	Cp	CC/Pp	CC/pp	Cc/Pp	Cc/pp
		sable	ped	sable	ped
	cP	Cc/PP	Cc/Pp	cc/PP	cc/Pp
		sable	sable	albino	albino
	cp	Cc/Pp	Cc/pp	cc/Pp	cc/pp
		sable	ped	albino	albino

More than one way being 'albino white'

Mutations on the C-locus drastically reduce phaeomelanin production and mutations on the P-locus do likewise to eumelanin production. Hence an animal being homozygous recessive on both the C and P locus won't have much if any pigment to colour its coat. It will be virtually indistinguishable from the 'classic' albino - genotype cc.

Mating chinchilla grey carrying albino to Pink-eyed-dilution carrying albino

		pink-eyed-			
		dilution			
		Cc/pp			
chinchilla					
grey	chcPp				
		Cp	Cp	cp	cp
	ch/P	Cch/Pp	Cch/Pp	chc/Pp	chc/Pp
		sable	sable	grey	grey
	ch/p	Cch/pp	Cch/pp	chc/pp	chc/pp
		p-e-d	p-e-d	white	white
	c/P	Cc/Pp	CcPp	ccPp	cc/Pp
		sable	sable	albino	albino
	c/p	Cc/pp	Cc/pp	cc/pp	cc/pp
		p-e-d	p-e-d	albino	albino

- Genetic contribution of parent one:
  Cc (full colour) and pp (pink-eyed-dilution) carries albino
- Genetic contribution of parent two:
  chc (chinchilla) carries albino, Pp carries pink-eyed-dilution
- Offspring genotype possibilities: Cch/Pp, chc/Pp, Cch/pp, chc/pp, cc/pp
- Offspring phenotype possibilities: sable, grey, pink-eyed-dilution, white, and albino.

Mating 'chinchilla grey' to 'pink-eyed-dilution' carrying albino - c

		pink-eyed-			
		dilution			
		Cc/pp			
chinchilla					
grey	chch/Pp				
		Cp	Cp	cp	cp
	ch/P	Cch/Pp	Cch/Pp	chc/Pp	chc/Pp
		sable	sable	grey	grey
	ch/p	Cch/pp	Cch/pp	chc/pp	chc/pp
		p-e-d	p-e-d	white	white
	ch/P	Cch/Pp	Cch/Pp	chc/Pp	chc/Pp
		sable	sable	grey	grey
	ch/p	Cch/pp	Cch/pp	chc/pp	chc/pp
		p-e-d	p-e-d	white	white

- Genetic contribution of parent one:
  Cc (full colour) and pp (pink-eye-dilution) carries albino
- Genetic contribution of parent two:
  chch (chinchilla) and Pp (carries pink-eyed-dilution)
- Offspring genotype possibilities: Cch/Pp, chch/Pp, Cch/pp, chc/pp
- Offspring phenotype possibilities: **sable, grey, pink-eyed-dilution, white**.

Mating 'chinchilla grey' to 'pink-eyed-dilution' carrying chinchilla ch

		pink-eyed-			
		dilution			
		Cch/pp			
chinchilla					
grey	chch/Pp				
		Cp	Cp	chp	chp
	ch/P	Cch/Pp	Cch/Pp	chch/Pp	chch/Pp
		sable	sable	grey	grey
	ch/p	Cch/pp	Cch/pp	chch/pp	chch/pp
		p-e-d	p-e-d	white	white
	ch/P	Cch/Pp	Cch/Pp	chch/Pp	chch/Pp
		sable	sable	grey	grey
	ch/p	Cch/pp	Cch/pp	chch/pp	chch/pp
		p-e-d	p-e-d	white	white

- Genetic contribution of parent one: Cch (full colour) and pp (pink-eyed-dilution) carries chinchilla
- Genetic contribution of parent two:
  chch (chinchilla) and Pp (carries pink-eyed-dilution)
- Offspring genotype possibilities: Cch/Pp, chch/Pp, Cch/pp, chch/pp
- Offspring phenotype possibilities: **sable, grey, pink-eyed-dilution, white**.

Brown

***Oculocutaneous albinism type 3* - OCA3**

- ***B = black eumelanin - dominant***
- ***b = brown eumelanin - recessive***

The final step in eumelanin synthesis converts brown pigment into black pigment. If this last step doesn't happen eumelanin stays brown - *the brown mutation*. The resulting coat colour is 'chocolate' or 'liver' or 'taupe' etc., depending whether you are a cat or a dog or a bird, etc. The colour of the eyes may be affected as well. The irides may be grey and the eyes may appear dark ruby as a result of iris transillumination.

In the brown mutation hair pigment is often reduced with age when coat colour turns 'grey'. I believe that my friend Teddy, a ferret of course, exactly fits this picture. (See photo 10.1 ferret Teddy, one year old and photo 10.2 three years old) His irises are grey but the eyes appear to be ruby (iris transillumination). Up to the age of three his guard hair was brown. But with the following spring moult most the hair on the hindquarters turned white giving him the 'grey look'. Probably after another moult or two Teddy will be 'grey' all over. If he lives long enough his fur could become almost white.

Photo 10.1 **Ferret Teddy,** one year old,

Photo 10.2 **Ferret Teddy,** 3 years.

Ferret Teddy in the photo and Papa Putorius fit the number 3 Punnett Square in chapter 5. Both are examples of the *brown phenotype.*

The B-locus codes for TYRP1, an enzyme that catalyses the final step in eumelanin production changing brown pigment to black pigment. It is believed when brown is expressed that the final step in eumelanin production has not taken place, hence the pigment remains brown. The mutant of this locus has a lightening effect on eumelanin (black) based colours only. It has no effect on phaeomelanin (red) based colours. The eumelanin of the hair is brown rather than black. The pigment granules also appear brown rather than black and are smaller and rounder in shape than black pigment granules. Mutations on the B-locus have been well documented in laboratory mice as well as humans.

		dark sable			
		BbCc			
dark sable	BbCc				
		BC	Bc	bC	bc
	BC	BBCC	BBCc	BbCC	BbCc
		dark sable	dark sable	dark sable	dark sable
	Bc	BBCc	BBcc	BbCc	Bbcc
		dark sable	albino	dark sable	albino
	bC	BbCC	BbCc	bbCC	bbCc
		dark sable	dark sable	brown	brown
	bc	BbCc	Bbcc	bbCc	bbcc
		dark sable	albino	brown	albino

Can two albino parents have non-albino offspring?

I suppose one way it could happen is if the two parents have mutations in different genes. For example, if one parent has albinism because of mutations in the C (tyrosinase) gene and another has albinism because of mutations in the P (pink-eyed dilution) gene, then their offspring would be carriers for both forms of albinism but not have either condition themselves.

Mutation on the C gene lead to ***Oculocutaneous albinism type 1 - OCA1,*** *mutations in the P gene lead to* ***Oculocutaneous albinism type 2 - OCA2.*** *In Caucasians, the amount of colour can vary a lot with blue eyes and blonde or even red hair possible. In Africans, there is an even wider distribution of colours. The difference has to do with what specific mutation the person has and with what their genetic background is and what are the other genes that can affect melanin production (or the P gene itself). Given the wide range of effects in people, I imagine there would be a wide range of effects in animals too.*

It is also possible, although rare, for a back mutation to happen. This is where a DNA change happens that can convert a mutated allele back to a wild type one.
From, ***Ask a Geneticist Staff, Stanford University, California.***

		albino
		ccPP
pink-eyed-dilution	CCpp	
		cP
	Cp	CcPp
		full colour

Albino parent does not carry pink-eyed-dilution and pink-eyed-dilution does not carry albino - offspring possibilities - all offspring will be coloured and are carriers of both, albino and pink-eyed-dilution.

		albino	
		ccPp	
pink-eyed-dilution	Ccpp		
		cP	cp
	Cp	CcPp	Ccpp
		full colour	pink-eyed-dilution
	cp	ccPp	ccpp
		albino	albino

Albino parent carries pink-eyed-dilution and pink-eyed-dilution parent carries albino - Offspring possibilities - full colour, pink-eyed-dilution, and albino.

Sources:

The Jackson Laboratory, http://www.informatics.jax.org/

Silvers, W. K. '*The Coat Colors of Mice*', *Springer* Verlag 1979, adapted for the Web by 'Mouse Genome Informatics', The Jackson Laboratory, June 2003, Revised January 2008.
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http://albinismdb.med.umn.edu/

British Journal of Ophthalmology 1998; **82:189**-195 (February) Albinism: modern molecular diagnosis,
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Alaska Science Forum,
Sue Ann Bowling, http://www.gi.alaska.edu/ScienceForum/cats.html
John Zasada, http://www.gi.alaska.edu/ScienceForum/ASF4/433.html

Merck Source,
http://www.mercksource.com/pp/us/cns/cns_home.jsp (search Albinism)

Emedicine: *Albinism* http://www.emedicine.com/oph/topic315.htm

Chapter Eleven

Dark-Eyed-White

When we think of eye colour we think of the beautifully pigmented irises in humans. But there is a lot more pigment in the eye than that. Pigment is formed in several parts of the vertebrate eye. The interior of the eye contains much black pigment in the **uveal layer**. Its function is to improve the image on the retina by reducing reflected light within in the eye, just like the black paint inside the old cameras. To this fact the blackness of the pupil is of course due. This is true for all vertebrate eyes. (Figure 11.1)

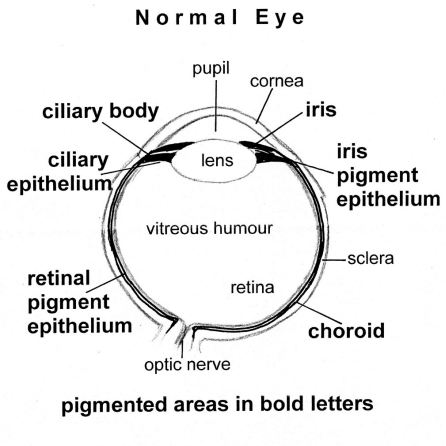

Figure 11.1

The iris regulates the amount of light that the pupil lets in the eye in two ways. One, pigment in the iris reflects light. Two, the circular muscle of the iris controls the size of the pupil so that more or less light, depending on conditions, is allowed to enter the eye. But if the iris lacks pigment there are two possible outcomes.

- ***eye colour is pink, like in albino animals.***
- ***eye colour is deep black, like in Dark-Eyed-White animals.***

The case of the albino animal is a simple one. Although albinos have a full compliment of pigment cells or melanocytes but what they lack is tyrosinase, the enzyme for synthesising pigment, hence white fur and pink eyes. Their eyes appear pink because of reflections from blood vessels within the eye, visible only because normal pigment in the eye is missing. (Figure 11.2)

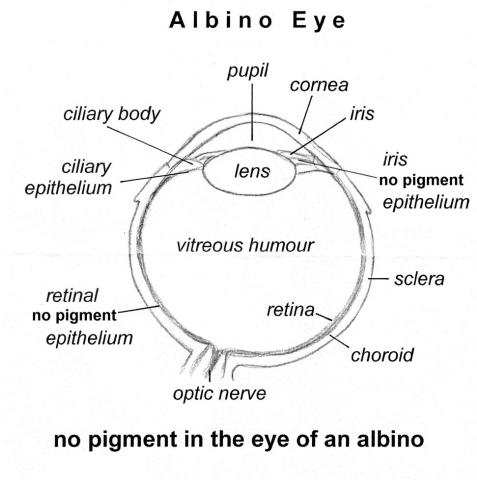

Figure 11.2

The case of the Dark-Eyed-White, sometimes referred to as Black-Eyed-White is more complicated. Even though they do have the enzyme for synthesising pigment but what they lack are melanocytes. Melanocytes are the home of melanosomes the factories of pigment production.

How then is it possible for Dark-Eyed-Whites to have those shiny deep black eyes? It starts with the migration of neural crest cells (stem cells). The ones we are interested in are melanoblasts, the precursors of pigment cells. The neural crest has two major segments,

- the **Trunk (sacral) Neural Crest (TNC)** and
- the **Cranial (mesencephalic) Neural Crest (CNC).**

Pigment cells of the eye have two origins. The retinal pigment epithelium, the iris epithelium and the ciliary epithelium are derived from the CNC. On the other hand, melanocytes in the iris, ciliary body and choroid are derived from the TNC.

Now it becomes interesting, because the TNC not only delivers pigment cells to the three regions in the eye - iris, ciliary body and choroid, but also to skin, hair, inner ear. As it happens, sometimes things go wrong. Melanoblasts from the TNC don't reach their destination to become pigment cells. The visible result is - white hair and skin, and no pigment in the iris. But if those cells don't reach the inner ear as well, the animal will be deaf. This explains why white coat colour is sometimes associated with deafness.

But the story doesn't end here. If things go wrong with melanoblasts from the TNC and the animal ends up with white fur, and no pigment in the iris and choroid, the same isn't necessarily so with melanoblasts from the CNC in the same animal. If the melanocytes from the CNC reach their destination in the eye and become pigment producing cells then some of the inner layers of the eye, retinal pigment epithelium, the iris epithelium and the ciliary epithelium will be black. This blackness can be seen through the pupil and the transparent iris. Remember, pigment in the iris reflects light - no pigment in the iris - light can enter the eye and will be absorbed by the black layers in the interior of the eye rendering its colour a deep shiny black. (Figure 11.3)

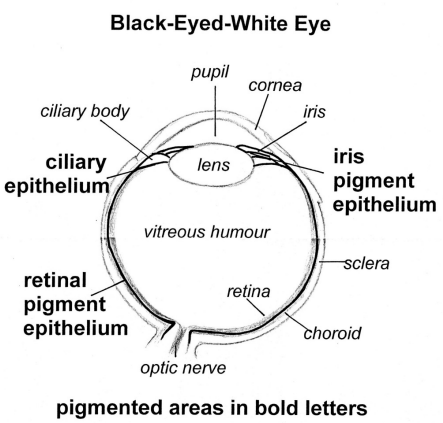

Figure 11.3

Uveal Layer of the Eye

The eye is a sensory organ responsible for vision. It can be divided into three layers that surround the fluid-filled spaces (vitreous humour the main body of the eye, and the aqueous humour behind the cornea). These layers include cornea/sclera the outer layer, the uvea in the middle, and the retina the inner layer.

The **uvea** (Latin, *uva,* meaning grape) is the innermost of the three concentric layers that make up the eye. The name is possibly a reference to its almost black colour, its wrinkled appearance and grape-like shape when stripped from a cadaveric eye. Its use as a technical term in anatomy is relatively modern.

Source:

Abzhanov, A., *et.al,* 'Dissimilar regulation of cell differentiation in mesencephalic (cranial) and sacral 9trunk) neural crest cells in vitro', Department of Genetics, Harvard Medical School, Boston, MA, USA, 2003.
The Company of Biologists Limited,
http://dev.biologists.org/cgi/content/full/130/19/4567

Chapter Twelve

‘Redheads’ *or* Erythrism

A cross species summary.

Redheads occur in a wide range of animals, not just humans. Dogs, birds, foxes, pigs, horses, cows, mice, squirrels, and many more, even the odd ferret or European polecat can have the mutation of a gene that cause red coat colour. There are many terms for red coat colour; it all depends to which species you belong.

If you are **Sorrel** or **Chestnut** you are a **horse**, if **Cinnamon** you might be a **ferret**, if **Golden** or **Yellow** you may be a dog or a mouse. And if you are **Fawn** or **Orange** I bet that you are a **rabbit**. This is confusing, because all of them have one thing in common they have the red coat colour version of the **MC1R** (melanocortin 1 receptor) also known as the **extension locus.** No matter what coat colour everyone has this gene, as it is responsible for the extension of black pigment in the hair.

The Extension Locus **MC1R *or* E-Locus**

The product of the **extension** locus is the melanocyte-stimulating-stimulating receptor or **melanocortin 1 receptor** (**MC1R**)**.** MC1R is found on the surface of the melanocytes controlling their production of **tyrosinase**. Tyrosinase is the limiting enzyme in the production of melanins. Low levels result in phaeomelanin synthesis while high levels result in eumelanin synthesis.

When the MC1R protein is just sitting around, doing nothing, tyrosinase levels are low, and the cell produces phaeomelanin, but when the small, blood-borne protein **alpha-melanocyte stimulating hormone (MSH)** binds to the MC1R receptor, the receptor tells the melanocyte to increase the level of tyrosinase inside it, causing the cell to produce eumelanin. MSH is produced in the pituitary gland.

Since MSH is always present in mice, dogs, ferrets, etc., in the absence of any other genes, the animal would be black from head to tail and colour genetics the simplest topic in the world.

The letter *E* (dominant) in a punnett square stands for normal extension of black. The letter *e* (recessive) for non extension of black. Thus, animals with red coat colour have a variant of just one gene. They have little or no black pigment (eumelanin) in their hair, instead they have often more than the usual amount of red/yellow pigment (phaeomelanin). The red hair version of this gene has slight changes that cause the red

hair colour. If only one of your MC1R copies has these changes, you won't have red hair, but you will be a carrier of the red hair gene. *EE* or *Ee* no red hair - *ee* red hair (erythrism).

		'redhead'	
		ee	
full colour	Ee		
		e	e
	E	Ee	Ee
		full colour	full colour
	e	e	e
		redhead	readhead

One parent is 'red' the other is not but carries the 'red hair gene'.
Offspring possibilities - non-reds but carriers (heterozygous), and redheads.

		full colour	
		Ee	
full colour	Ee		
		E	e
	E	EE	Ee
		full colour	full colour
	e	Ee	ee
		full colour	redhead

Both parents are non-reds but are carriers of the red hair gene (heterozygous).
Offspring possibilities - non-reds, which are not carriers (dominant homozygous), non-reds, which are carriers (heterozygous) and redheads (recessive homozygous)

		redhead
		ee
full colour	EE	
		e
	E	Ee
		full colour

One parent non-red (dominant homozygous) the other parent a redhead.
Offspring possibilities: all full colour (heterozygous) but carriers of 'red'.

Ferrets and Polecats and Humans

In her paper *'Notes on the genetic behaviour of certain characters in the polecat, ferret, and in polecat ferret hybrids*.' (1921), Frances Pitt describes erythristic mutations in the European polecat as follows: 'In this variety the black pigment is entirely suppressed, leaving the animal a beautiful reddish colour.' and compares them to a similar fawn-coloured variety of the ferret. These mutations, Pitt says, we may safely assume it to be due to the loss a black pigment factor.

Erythristic polecats in which dark guard hairs are replace by red ones were found in Britain, a phenotype probably derived from an allelic variant of Tyrosinase, producing phaeomelanin. (Lode)

'Red hair' is a great example of a recessive allele. There's a protein called MC1R, and one of its usual jobs is to get rid of red pigment. When it isn't working, you get a build-up of red pigment and end up with red hair.

'All it takes to keep from having red hair is a little bit of MC1R protein. So it's easy to see why red hair is recessive. As long as you have one working MC1R gene, you won't have red hair. The working protein picks up the slack. If both copies of your MC1R gene code for broken proteins, then you'll have red hair.'

Sources:

'The Melanocortin 1 Receptor (MC1R): More Than Just Red Hair' J.L. Rees, University of Edinburgh, Edinburgh, United Kingdom, Pigment Cell Research, Volume 13 Issue 3 Page 135-140, June 2000.

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Chapter Thirteen

Melanism - Black Ferrets?

Why not? Just as albinos pop up from time to time in many species so do all black or melanistic individuals. Melanism is a term for animals that are darker than normal. There are black dogs, black cats, black squirrels, black mice, rats, and more.

If you are a cat and you are black you have a definite advantage in terms of health, scientists say. Black cats are more resistant to viral infections and thus generally healthier than their paler counterparts. Why? Coat colour gene mutations involved might play a part in controlling disease. This should not surprise us because we already know that coat colour can go hand in hand with certain condition as well. To name a few, albinism correlates with eye problems, white spotting with hearing problems, extreme white can be fatal, dominant yellow in mice with overeating and obesity, and so on. Dilution is implicated with impaired immune systems. Recent studies have shown that coat-colour genes do have an effect on the immune system. Types of receptors involved in coat colour are also used by viruses to enter cells.

What is Melanism?
Melanism is the opposite of albinism.

Melanism is relatively common in a number of felids. Leopards and jaguars with this condition are often called ***black panthers***. But not all black cats are the same. So far we know that two completely different mutations lead to black coat colour, not just in cats but other mammals as well. An example is the well-researched rock pocket mouse, *Chaetodipus intermedius.* The phenotype in different populations of black rock pocket mice is the same but their black coat colour is the result of different genotypes. One is a mutation on the agouti locus (A) the other on the extension locus (MC1R).

The mutation on the **agouti locus is recessive**. Meaning that two black parents will always produce black offspring.

Genotype *a/a* = phenotype *black*

		black	
		aa	
black	aa		
		a	a
	a	aa	aa
		black	black
	a	aa	aa
		black	black

If two normal coloured parents are carriers of the recessive mutation they can produce both, black and normal coloured offspring.

		not black	
		Aa	
not black	Aa		
		A	a
	A	AA	Aa
		not black	not black
	a	Aa	aa
		not black	black

The mutation on the **extension locus is dominant**. Meaning that two black parents can have both, black and normal colour offspring.

		black	
		E+E	
black	E+E		
		E+	E
	E+	E+E+	E+E
		black*	black
	E	E+E	EE
		black	not black

* Keep in mind that the homozygous state of dominating genes is often lethal, resulting in a reduced litter size when heterozygotes are mated.

Genotype *E+/E* = phenotype *black*
Genotype E+/e phenotype *black*

Two parents of normal colour won't produce black offspring. But nothing is impossible in genetics - spontaneous mutations do happen - bingo two normal coloured parents have a black sheep, sorry, I meant to say, black offspring.

Apart from those mutations some animals simply have larger black spots or stripes, which merge and give a black appearance. This condition is not melanism; it is called abundism or pseudo-melanism. For example black tigers and black zebras have thick stripes so close together that the tawny or white background is barely visible between stripes.

Are there any Black Ferrets?

I cannot say but it is quite possible. And if there are no black ferrets now all we have to do is wait - sooner or later black ferrets will pop up. And if the black pussies are any guide black ferrets will be healthier than their paler counterparts.

How to Identify the Black Ferret?

I say look at the guard hair. If they are all black from tip to base, that is, no agouti banding in any of the guard hair, than my bet is that this ferret is melanistic - we could call it a **Melano**.

Sources:

The Jackson Laboratory, http://www.informatics.jax.org/

Silvers, W. K. '*The Coat Colors of Mice', Springer* Verlag 1979, adapted for the Web by 'Mouse Genome Informatics', The Jackson Laboratory, June 2003, Revised January 2008.
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'*Black cats may be the more fortunate felines',* S. Bhattacharya, New Scientist, 04 March 2003

Chapter Fourteen

Salt and Pepper or Pepper and Salt?
Roan - Grey - Silver

In ferret literature the term roaning is often wrongly applied to describe progressive greying with age. Many animals, including humans, may have a mix of white and pigmented hairs, as they get older. But they are not necessarily roan even though they look roan and are easily mistaken for roan.

What is Roan?

Roan is a coat colour pattern in which the pigmented guard hair is intermingled with white hair. The amount of roaning can vary from minimal where it is barely noticeable to very pronounced where most hair is white. Obviously, roan always appears to be lighter than the background colour. The base colour can be any colour - black, brown, red, yellow.

A roan is not always a horse. It can be a dog, or a cow, a mouse, a goat, and of course a ferret, but not a human or a cat. That is what the literature says.

Roan is present at birth or, if you are a ferret and born naked it will manifest itself in your first full coat. The proportions of white and pigmented hair stay the same throughout your life provided you don't have the greying gene. For example, it is possible for an individual to be both roan and grey.
Roans which also inherit the greying with age gene eventually may become completely white. Their eyes however retain their dark colour - 'Greyed out Roan' or Black-Eyed-White.

What looks Roan but is not Roan?
You are not roan if you were born with a natural coat colour without any white guard hair, but as time passes you begin to look like a roan as more and more of your guard hair becomes white - this is 'greying with age'. The coat colours roan, and greying with age are often lumped together. But why be so fussy? Because the genetics of roan and greying are different. Roan is a mutation on the KIT gene and it ligands, like white spotting and piebald. White hairs in roan have no pigment cells to produce pigment. But white hairs in greys have pigment cell only they don't switch on anymore to produce pigment.

The Genetics of Roan
Roan in horses is dominant and probably lethal in homozygotes. A roan foal will always have a roan parent. The symbol for roan is *Rn.*

Roan in mice is semi-dominant. Homozygotes appear very light grey, with a much higher proportion of white hairs than heterozygotes.

Roan in dogs certainly exists but how it is inherited is not quite clear at this stage.

Roan in cattle is co-dominant. For example in one breed of cattle when crossing white and red colours the result is not a calf that is white or red but roan - a mix of white and red hair. WW (white) and ww (red) equals Ww (roan) a perfect example of co-dominance.

A homozygote is an individual that has two identical alleles of a gene. In contrast to a heterozygote which has two different versions of a given gene for a particular trait.

Roan in Ferrets
Difficult to say without having access to reliable breeding records whether a ferret born with a coat colour of a mixture of white guard hairs and dark guard hairs is roan or something else. If roan in ferrets is like roan in horses then every roan ferret has a roan parent and grandparent and great-grandparent and on and on. If roan is lethal in homozygotes then mating two roans would lead to reduced litters.

If the gene is semi-dominant like in mice no problem. About roan in dogs we know very little. And roan like in cattle has not to my knowledge been found in ferrets so far.

But if two non-roan parents have a kit or kits with a mix of dark and white guard hair these kits are not roan. They are probably 'silver'. Silver (Si) is recessive, ergo; both parents carry the gene without showing the trait, like two sable parents producing albino kits.

'Silver' as in Mice
This mutation affects the viability of melanoblasts, resulting in random occurrence of **white, partially white or grey hairs, and fully pigmented hairs** that together display as varying intensities of silvering. In general silver mice become progressively more silvered as they age, but in some silver mutations the silvering decreases as the animal gets older.

'Silver' in Ferrets?
Accurate breeding records and reliable observation of the aging individual's coat colour are needed to confirm the existence of this mutation in ferrets. But what does not exist today may show up tomorrow.

Sources:

The Jackson Laboratory, http://www.informatics.jax.org/

Silvers, W. K. '*The Coat Colors of Mice*', *Springer* Verlag 1979, adapted for the Web by 'Mouse Genome Informatics', The Jackson Laboratory, June 2003, Revised January 2008.
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Alaska Science Forum,
Sue Ann Bowling, http://www.gi.alaska.edu/ScienceForum/cats.html

Chapter Fifteen

Dilution

The D-Locus

- ***D = normal pigmentation - dominant***
- ***d = dilution - recessive***

Synonyms: Dct, DOPAchrome tautomerase, DT, TRP-2, tyrosinase-related protein-2, Tyrp-2, Tyrp2.

Mutations at the D-locus have a dilution effect on genotypes that otherwise provide for an intensely pigmented coat colour. Diluted black eumelanin is grey, diluted brown eumelanin is light brown, whereas the red phaeomelanin when diluted takes on a creamy colour. This effect is not due to a reduction in the amount of pigment in the hair. To the contrary, mutations at the D-locus result in phenotypes that may have more hair pigment than the corresponding non-dilute animals but the pigment is deposited into a few very large clumps. These clumps have little effect on light absorption. (See figure 15.1)

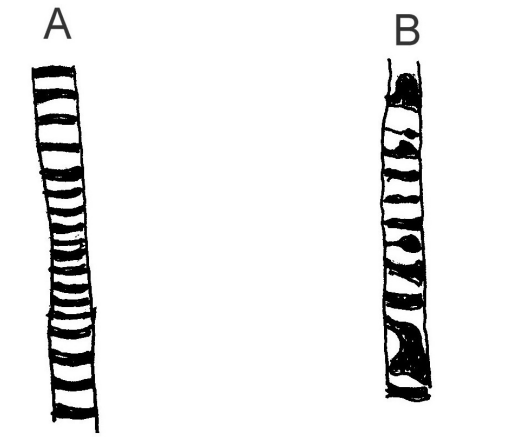

Figure 15.1

Dilution creates very attractive pastel coat colours such as in the Aleutian mink, the beige mouse, blue and silver foxes, and the blue Persian cat. Dilution has also been documented in humans, Hereford and Brangus cattle and killer whales.

Pastels come at a Price

Compromised immune system - pus-producing infections - platelet deficiency prolonged bleeding - neurological disorders - ‘screw neck’ in mink - kidney and liver

failure - tumours - shortened lifespan. Dilution in humans is associated with Chediak-Higashi Syndrome (CHS) a fatal genetic disorder. Humans with CHS usually die during childhood.

Dilution in Ferrets?
If the mutation does not already exist, one day it will happen for sure. Since the mutation is a loss of function and therefore recessive inbreeding will eventually produce this phenotype including all the health problems associated with this mutation.

Note: D-locus dilution must not be confused with 'Extreme dilution' on the C-locus or Pink-eyed-dilution on the P-locus or 'greying with age'.

Sources:

Silvers, W. K. '*The Coat Colors of Mice*', *Springer* Verlag 1979, adapted for the Web by 'Mouse Genome Informatics', The Jackson Laboratory, June 2003, Revised January 2008
http://www.informatics.jax.org/wksilvers/frames/frame4-1.shtml

The Jackson Laboratory, http://www.informatics.jax.org/

Chapter Sixteen

Greying with Age

It's not unusual for a ferret to lose its original coat colour over time. The ferret becomes grey or even white with age. The speed at which that happens varies. In some individuals this can happen very quickly. But premature greying in ferrets is no cause for alarm. Greying with age afflicts humans, too. Some see greying to be a sign or maturity but for most humans it is a cosmetic blight. Every human, provided they live long enough or don't lose all their hair first, will eventually turn grey or white. Ferrets who once were in a particular coat colour category eventually became reclassified as 'other colours'.

How does hair grow?

There are three stages in the life cycle of a hair. They are called *anagen, catagen, and telogen.*

- Anagen is the active growth stage.
- Catagen is the transitional stage when hair growth starts to shut down, including pigment production.
- Telogen refers to the stage when hair growth is completely at rest and the hair falls out.
-

After the telogen phase the hair growth process starts again with the anagen phase. However it can happen that for some reason the pigment production does not commence and the new hair is without colour. It is white. In ferrets this may lead to progressive 'greying' after every moult as pigment production in more and more hair follicles fail to switch on.

How hair gets its colour

Hair gets its colour from a pigment called melanin. Hair has two types of melanin, the black and brown eumelanin, and the red and yellow phaeomelanin. They blend together to give us a wide range of hair colours. The natural colour of hair depends upon the type, distribution, and amount of melanin in the hair shaft. Melanin is made by special cells called melanocytes found in hair follicles from which hair grows.

Why does hair lose its colour?

We know that grey hair results from a reduction of pigment, while white hair has no pigment at all. But exactly why the melanocytes in stop making melanin we don't know. Strictly speaking, grey hair is not really grey. It is the mix of dark and white hair giving an overall 'grey' impression. Thus ferrets starting out with a pale coat colour don't turn grey they become white. The same happens to humans with blond hair, they simply turn white with age. Red hair doesn't become grey; it usually becomes a sandy colour before turning white.

Of Horses and Mice and Men and Ferrets

Not only humans and ferrets might become grey or white with age but so do horses and mice. I have singled out horses and mice because in those two species the greying process has been researched and scientists have come up with some unexpected results.

Greying in horses

Ga - greying with age gene, dominant, Ga/- horses of any colour will become grey with age.
g - non-greying gene, g/g horses will not become grey.

Greying horses occur in all horse breeds but the most famous of all greying horses is the Lippizaner a breed of greying horses. All greying horses are born coloured, usually black or brown or chestnut, but by the age of 10 most are completely white except for their skin and eye colour. Greying horses pay a prize for their attractive coat colour - melanoma. After the age of 10 nearly all of them develop tumours. Greying is attributed to the dominant 'greying with age' or Ga gene found on horse chromosome 25. The grey mutation has probably occurred only once thousands of years ago and eventually spread though all horse breeds. Scientists are searching for a possible biochemical between the development of this particular coat colour and tumours. In non-greying horses melanomas are rare.

Based on the present state of knowledge the greying phenotype in horses may be caused by a mutation unique to horses as no obvious candidates for the grey gene have been identified in other mammalian species.

Greying in mice

Just like people, ferrets and horses, some mice, too, become grey with age. While looking for the greying gene in mice, researchers made a surprising discovery.

In 1970 researchers found mice that become grey with age amongst wild mice in South Australia. At first the condition was ascribed to a dominant mutation like the Ga gene in horses. But something strange happened during test matings. All offspring of greying mothers and non-greying fathers were grey by the age of 10 months. On the other hand very few of the offspring of non-greying mothers and greying fathers became grey with age.

Eventually scientists established that the greying with age in those mice was traceable to a leukaemia virus that causes melanocyte dysfunction. The virus is transmitted mainly in milk and is the likely candidate for the greying condition previously ascribed to the Ga gene.

Greying in humans

Almost nothing is known about the genes involved in greying hair. But having teenage children is a factor according to greying parents. Other factors that can influence hair colour apart from genes, viruses and age are: hormones, climate, pollutants, toxins, chemicals and even were the hair grows on the body.

Greying in ferrets

There are many greying ferrets but we know next to nothing about the cause or causes. Is it the 'Lippizaner effect'? Is it a virus? Is it a consequence of domestication? Troublesome owners, something in the food, water, air, or is it something we haven't thought of it yet? Is it a combination of factors? I cannot say.

Given that greying is so common in people and ferrets still we know so little about it let alone to prevent it. But rest assured the condition is not life threatening.

Greying must not be confused with roan. Although roans can become grey with age, like any other coat colour.

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Chapter Seventeen

Ghosts in your Coat Colour Genes

Don't be too surprised if the coat colours in your litters are not what you expected.

Genetics may look tricky but it really comes down to a few basic points. We have two copies of most of our genes, one copy from mum and one from dad. Those genes can come in different versions. The colour you end up with is dictated by these different versions - ***except when you end up with a different colour.***

Just when I thought I have come to grips with the basics of genes and coat colour I come across some weird things. An animal's DNA may 'remember' a gene from a few generations back and end up with that colour instead of the one its genes tell it to have. This is called paramutation.

Ghost number one - *Paramutation*

Paramutation was first noted in corn. Sometimes the purple colour found in corn followed the rules of genetics. And sometimes it didn't.

Now scientists have discovered something similar in mice and the colour of their tail tips. Sometimes a mouse will have a white tail tip even when a mouse's genes tell it not to. All mammals have a gene called 'kit'. Amongst other things, the kit gene affects the colour of the tip of a mouse's tail. Kit genes come at least in two versions, let's call them K and k. If a mouse has two K versions it has a solid coloured tail. If it has one K and one k than it has a white tail tip. Two k versions in mice are lethal; they will die soon after birth.

By mating a white-tipped mouse with a solid coloured one, one would expect that half of the mice have a solid coloured tail. Not so. In controlled experiments nearly all of the mice ended up with a white tipped tail, both the Kk *and* the KK mice.

As it happened some of the mice overcame their genes and ended up with a trait not dictated by their genes.

How do mouse cells "remember" that one parent had a white tipped tail? The researchers believe that it might have something to do with RNA.

To cut a very long story about the functions of RNA short, the story goes like that. A gene is just a recipe for a protein. The kit gene is a recipe for the kit protein. Before the information in a gene is used to make a protein, the DNA sequence is first copied into RNA and then translated into proteins. But that's not all. There are several forms of RNAs. Some RNAs never code for proteins but instead control the RNAs that do. They have the capacity to disable a gene's RNA before it can copy the information of the gene and transcribe it into protein.

A gene without functional RNA is like a gene that doesn't exist or - to use an analogy - like a recipe without the cook to bake the cake.

The gene is the recipe. Its RNA is the cook. The protein is the finished cake. Knock out the cook - NO CAKE. Good idea to have two cooks or two versions of each gene, so you don't miss out altogether.

How does this apply to the white tipped mouse tails? The k gene of the Kk mouse, that is the mouse with the white tipped tail, makes no useable kit RNA. Therefore the Kk mouse has only half the amount of kit RNA than the KK mouse, that is the mouse with the solid coloured tail.

If there were some way to decrease the amount of RNA in a KK mouse, then it might end up with a white tipped tail. Researchers think that the sperm or egg from mice with white tipped tails have RNAs that destroy some of the kit RNA. A mouse that results from such a sperm or egg would make less kit RNA even if it is a KK mouse and end up with a white tip on its tail.

Perhaps one day we may understand why we are all so different from each other provided we come to grips with DNA and RNA and everything else in the genome.

Genes are pieces of DNA, and most genes contain the information for making a specific protein. Except that the concept of discrete genes as beads on a DNA string is fading fast. It seems that genes, the protein coding sequences, have no clear beginning or end and RNA is a key part of the information package of overlapping transcripts where weird and wonderful things can happen like in the cress plant *Arabidopsis.* Mutated cress plants are somehow inheriting DNA sequences from their grandparents that neither of their parents possessed - which is supposed to be impossible.

These plants had replaced the abnormal DNA sequence with the regular code possessed by earlier generations. Can this happen in mammals? Who knows, Albino parents producing non-albino offspring? The ferret kitten replacing its mutated DNA sequence with the normal sequence of a coloured forebear. Spooky! Keep in mind, though, that these scenarios are rare but technically possible.

What's true for the kit gene may be true for all other genes not only in mice or corn but also in the animal and plant kingdom as a whole.

There is more that can affect the coat colour. What your mother has eaten may affect what colour your fur has even when your genes tell a different story. This is called **Epigenetics**.

Ghost number two - *Epigenetics*

Of course there is nothing unusual about mice with white tail tips except that the tails of the mice in question should have been solid coloured according to their genes. By a

process known as paramutation their genome remembered that a granddad had a white tail tip and - bingo - little Pips and Pops are sporting tails with white tips, too. I must add that neither mum nor dad of Pips and Pops had genes for white tail tips.

But if you thought that is strange there are stranger coat colour examples. Scientists have discovered they could change the coat colour of baby mice by feeding their mothers different levels of four common nutrients during pregnancy. What is striking - all pups and their mothers had the identical Agouti gene for coat colour, namely, viable yellow (A(vy)/a). (See image, 'Same genes, different colours. Blame it on what mum ate while pregnant')

Mice that carry the viable yellow (Avy) mutation, a dominant mutation of the agouti (a) gene, exhibit a phenotype that includes yellow fur, marked obesity, a form of type II diabetes, and an increased susceptibility to tumour development.

This startling scientific discovery demonstrates that we are more than what we eat - we are likely what our mothers ate, too, and what our grandmothers ate, and so on.

We are about to enter the wonderful and exciting world of epigenetics where nothing is predictable and anything is possible - good or bad.

Back to the mouse mothers and their pups. Four common nutritional supplements - folic acid, vitamin B12, choline and betaine were added to the diet of pregnant mice and sure enough these 'vitamin-enriched mothers' gave birth to pups with brown coats instead of yellow coats.

What is even more intriguing is that these four supplements had effects beyond coat colour, because the Agouti gene regulates more than just coat colour it also affects other aspects of metabolism. What the extra nutrients did was to reduce the expression dominant 'viable yellow' Agouti gene, to cause the coat colour change yet the gene itself remained unchanged. Furthermore the brown mice were also less susceptible to obesity, diabetes and cancer than genetically identical but yellow mice whose mothers received normal food. The non-supplemented mothers were not deficient in these nutrients.

This experiment shows the tightest link yet between food and this strange form of inheritance called epigenetics. The researchers discovered that this worked through a process called DNA methylation by which a gene can be switched on or off or its function altered. In DNA methylation certain chemicals - called a methyl group - become attached at a specific point to DNA either silencing a gene or reducing its expression inside a given cell. The mice with the dominant but silenced 'viable yellow' Agouti gene will develop just like other brown mice and will be brown and lean and healthy.

But the story doesn't end here. The brown mice in our story inherited genes for yellow coats thus; their offspring inheriting the genes for yellow ought to be yellow. Not necessarily so. A silenced gene, also known as 'imprinted' gene can be trangenerational, i.e. passed down to the next generation and the next, and so on. And what we are ending up with is individuals and families whose genotype doesn't match their phenotype. Brown-yellow mice or yellow-brown mice? Confusing!

One day, out of the blue, surprise, surprise an unexpected colour pops up in the litter. No, it wasn't the guy from the other den - for some reason DNA methylation was reversed and the gene switched on. Brown turned yellow or did yellow show it's true colour? Never mind!

'There is a lot more to inheritance than what Mendel found with his peas!'

Not by genes alone

Genes do not account for all the traits you inherit from your parents. As well as genes, all cells in your body carry a set of instructions that tell the genes when to be active. One way of doing this is by adding chemical markers to the DNA. This 'instruction manual' allows different cells to use the same set of genes to develop distinctive identities, liver cells, muscle cells, bone cells, and the rest. Whether or not some genes are active or not, especially those vital for health, may depend on what your mother or grandmother ate before she knew she was pregnant - or what chemicals your father was exposed to long before you were conceived. This makes the mice study such an intriguing one. Recent studies have shown that endocrine disruptors promote a number of disease states; one well-studied example is male infertility. Endocrine disruptors are chemicals such as fungicides, pesticides, and others that interfere with a cell's 'instruction manual'.

Epigenetics is the study of the chemical groups that stick to DNA and act as switches to turn genes on and off.
Epigenetic inheritance. From the Greek prefix epi-, which means 'on' or 'over', epigenetic information modulates gene expression without modifying actual DNA sequence. 'If you liken the genome to the hardware of a computer, then epigenetics is the software.' Epigenetic inheritance provides a rapid mechanism by which [an organism] can respond to the environment without having to change its hardware.' (Randy Jirtle, Ph.D., professor of radiation oncology at Duke and senior investigator of the study.)

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Chapter Eighteen

Coat Colour and Life Expectancy

Sable - Albino - Dilute Colour - Dark-Eyed-White

Sable
That sable ferrets live longer is not surprising. This coat colour has evolved over millions of years and stood the test of time. Geneticists call this coat colour the 'wild-type'. Any of the other colours are caused by mutations on one or more of the colour genes. Furthermore, in the early stages of embryonic development the expression of coat colour is subject to factors, which not only influence coat colour but other biological functions as well. Therefore, any coat colour other than 'wild-type' might harbour health problems.

Albino
The most familiar example of a connection between coat colour and health problems is the albino ferret. Not only is it white and has pink eyes but its vision is always compromised. Though, bad eyesight has no impact on longevity in domesticated animals.

Genesis of Colour

Coat colour is the product of two major mechanisms.

- In the embryo melanoblasts, the precursors of pigment cells (melanocytes) arise in the neural crest and migrate to their destination. Normally they are able to reach all parts of the body and the skin will receive its full complement of pigment cells.

- Pigment cells produce pigment by a complex chain of chemical reactions. The pigment in these cells is confined to organelles called melanosomes. The melanosomes are transferred into the growing hair to give it colour.

Mutations
There are three major mechanisms by which mutation can affect the pigmentation process.

- Mutations can affect the migration of melanoblasts. Melanoblasts may fail to reach their destination. Consequently some areas of the skin will be devoid of melanocytes and the hair in the affected areas will be white producing a piebald pattern. For example, the white ferret with a sable leg is really a sable ferret with a big white spot. A total absence of melanocytes results in a completely white coat, however, the eyes will be black. A good example of this mutation is the Dark-Eyed-White ferret. White spotting mutations occur in most domestic animals but not in wild animals.
- Mutations can affect the biosynthesis of pigment production causing various forms of albinism. The most common type amongst ferrets is oculocutaneous albinism

that is the complete absence of any pigment in the individual. Being albino doesn't necessarily coincide with a complete absence of pigment in the fur but is always coincides with poor vision. The Siamese cat is albino.

- Mutations can affect melanosomes resulting in dilute coat colours, usually an ashen or silvery grey or beige, depending on other coat colour genes. Whether or not dilution occurs in ferrets has not been established either way. It has been described in humans, mink, foxes, Persian cats, Hereford and Brangus cattle, mice, and killer whales. The beige mouse and the Aleutian mink exemplify the pigment dilution.

Dilution and Health

Dilute coat colour, as a result of abnormal melanosomes, comes with serious health problems. Mutations, which affect pigmentation, because of abnormal melanosomes, also affect lysosomes. Lysosomes are organelles found in most cells, especially in leukocytes (white blood cells) and liver and kidney cells. There is an increased susceptibility to bacterial infections due to an impaired immune system function, an increased tendency to bleed due to platelet granule defects, kidney dysfunction, and partial oculocutaneous albinism due to abnormal melanin distribution. Dilute coat colours might be pretty but life is often short for the 'coat owner'.

Whiteness and Health

Melanocytes originate in the **neural crest**. They migrate not only to the skin but also to the inner ear and eyes. The failure of melanocytes to migrate to these locations explains the association of congenital white spotting (piebaldism), and congenital deafness as in Waardenburg Syndrome characterised by a frontal white blaze - the 'Badger' marking in ferrets.

The deep black shiny eyes of the Dark-Eyed-White ferret, believe it or not, is a lack of melanocytes in the irises. In itself it is not a condition to influence longevity, however, it is a pointer that something might have gone wrong in the early stages of embryonic development.

An extreme case of white and ill health is the 'White Foal Syndrome'. The foals have blue eyes and are white at birth. Initially these foals appear normal except for their unusual colour. Soon troubling signs emerge. The foals can't pass faeces, caused by the lack embryonic cells that form nerves in the gastrointestinal system. Death is inevitable.

In order to understand what has gone wrong we have to go right back to the beginning. Before neural crest cells start their migration they are remarkably pluripotent. An individual neural crest cell can give rise to more than one cell type. We also call them **Embryonic Stem Cells.** Neural crest cells in the embryo contribute to a diverse set of nerve cells, smooth muscle cells including the major vessels of the heart, endocrine cells of the adrenal gland and most pigment cells.

Diluted Albino - White Albino?

If you are albino and you are deaf your deafness is not caused by the lack of pigment but by the lack of pigment cells. Albino ferrets can be piebald they can have Waardenburg-syndrome. Albino also can have a diluted coat colour including all the

health problems that come with 'too much white', except you can't see the white spots nor the diluted coat colour. Remember in every albino hides a coloured ferret - anything from robust sable to delicate Dark-Eyed-White.

Black
Black is good scientist say - if you are a cat. Black cats are more resistant to viral infection and therefore healthier than their pale counterpart. This could be true for ferrets, too, if there were black ferrets.

If I could chose the colour of my coat I would go for Black or Sable, Albino and Brown are not bad. But no way would I want to have Dilution or too much White-spotting.

Note: Polar bears are not a species of albino bears, nor are snow hares 'seasonal albino', because they don a white coat during the northern winter months. Yet, there might be albinos amongst them. White markings in wild animals like skunk, zebra, panda bear and other are of different origins than the white markings in domestic animals.

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Chapter Nineteen

Hair

Long - curly - short - soft - mole - angora - wavy - straight

What are coat types?
Not much attention has been given to coat types in ferrets until the angora ferret popped up in Europe. Many ferret people have reservation about angora ferrets. Some even go so far and say it is cruelty to breed such ferrets. Cruel or not I'm not entering this debate. But what I like to do is to give a description of various coat types in domestic animals.

In the wild animals have coat types that are best suited to their life style. For example, for mammals hunting in water for fish the fur is of great significance for regulating body temperature. The fur of seal, mink and otter not only has to be warm but also very durable and strong to last through the winter. Other mammals have warm fur, too, but the coat, for example of hare, foxes and the rest, do not need to be nearly as strong as those of the mammals hunting in the water. The right coat type for wild animals is a matter of survival.

But in captivity animals have the protection of humans and therefore can be bred for a particular coat types either for utility, or fashion, or curiosity. For example, wirehaired dogs were bred for chasing quarry through thicket. Their coarse coat protects their skin from injury. Angora rabbits are bred for their wool; Persian cats for shows; hairless dogs and cats for curiosity.

Mammals have several types of hair - coat hair, whiskers and eyelashes.
The wild type coat in most mammals has three types of guard hair. These are the long hairs that protect the soft undercoat and have a waterproofing function. The undercoat hairs are short, dense, soft and wavy, and act as insulation. (See figure 1)

Mole - Angora - Wirehaired
The ratio between the protective guard hair and the undercoat play a role in the appearance of an animal's fur. Some animals lack most or all guard hair but have an undercoat. As a matter of fact all they have is the undercoat. In mink this mutation is called 'mole'. Other have only guard hair and no undercoat these are the angora mutations, like the angora rabbit, angora ferret, angora cat, angora goat, etc.

Wirehaired mutations have an abundance of guard hair. The coat texture is coarse, crimped and springy. This mutation is found in many dog breeds, such as the wirehaired Dachshund, German Pointer, Hungarian Vizslar, Terriers, and many more, as well as in the *American wirehaired cat*.

Rex and Persian
A coat type is also characterised partly by the length and partly by the physical structure of its hair - long versus short - straight versus wavy or curly.

The 'rex' mutations slow the rate of hair growth; the result is that most the hairs are shorter than usual, thin and imperfectly formed. Most affected are the guard hair which are not much longer that the undercoat. The end result is short coat with a characteristically curly appearance, seen in Devon and Cornish Rex cats and also rats.
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The Persian cat is not to be confused with the Angora cat. Both have a long coat but the Persian is a longhaired cat with both, guard hair and undercoat, whereas the Angora has no undercoat but long guard hair, just like the Angora ferret. In the angora mutation the hair doesn't grow faster but the time the hair grows is prolonged resulting in longer hair.

Hairless
Some mammals are hairless, or nearly so - the Canadian Hairless Cat or Sphinx, the Peruvian Hairless Dog, and of course my people.

Coat types and genotypes
Wirehaired mutations are dominant. A wirehaired pup or kit has at least one wirehaired parent. But wirehaired parent can have non-wirehaired offspring.

All the other mutations, longhaired, wavy, rex, angora hairless are recessive. An individual can be a carrier of one or more of these traits and not show the trait or traits. Until one day two individuals who carry the same recessive traits mate and - surprise - surprise - some of the kits don't look like mum and dad at all.

Whiskers and Eyelashes
Whiskers are long sensory hairs that grow on the face around the muzzle and eyebrows of most mammals. Cats also grow whiskers on their paws. Whiskers are usually thicker and stiffer than other types of hair. They consist of inert material but are implanted in a special hair follicle sealed by a capsule of blood. Touching a whisker causes it to bend pushing the blood in the capsule in one direction or another thereby amplifying the movement, thus providing a warning of something is nearby. In many animals the follicles of their whiskers are imbedded in muscle tissue allowing the animal to move them.

Eyelashes grow around the rim of the eyelid and perform the same functions as whiskers. They, too, are sensitive to being touched. The eye closes reflexively when an insect or particle touches the eyelashes.

Source:

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http://kursus.kvl.dk/shares/vetgen/_Popgen/genetics/genetik.htm

Chapter Twenty

How do you Explain Patch‘s Unusual Pattern?

Photo 20.1 **Ferret Patch** SA

Is Patch is a white ferret with a large sable patch or a sable ferret with a very large white ‘spot’? Or strangest of all is Patch two ferrets in one?

I can think of three possibilities how Patch got this unusual coat colour pattern.

- Patch could be a case of extreme Irish spotting.
- He could be a ferret chimera.
- He could be a ferret mosaic.

Irish spotting is explained in chapter 9 ‘Whites‘

Ferret Chimera
A ferret who is a chimera has the DNA of two different ferrets. Some of the ferret’s cells have the DNA of one ferret and some have the DNA of another ferret. This sounds strange but chimeras are known in many species including humans. How can this happen?

Imagine that inside a ferret womb are a number of eggs. Each egg is fertilised by a different sperm cell - you get a litter of kits. The same happens in humans if there is more than one egg in the womb you get fraternal twins or triplets, or more.
Now, imagine that instead of developing separately, two of the fertilized eggs actually fuse. Instead of two only one ferret kit would develop. This kit would have cells from not one, but two different zygotes.

As we know every zygote carries its own unique set of DNA. Thus the ferret would have two different sets of DNA - this ferret would be a *chimera*. If the two different sets of DNA code for the same coat colour you wouldn't be able to tell the ferret was a chimera but if the DNAs code for different coat colours say one for sable and the other for albino you can tell from the distance this ferret might be a chimera.

You may ask shouldn't the fusion of two ferrets look different, let's say eight legs, two tails and two heads? No, this wouldn't happen because the fusion of the eggs takes place very early before the cells build body parts. After the fusion of two zygotes their cells, regardless of their different DNAs, divide as if they were all created from one zygote.

Patch might be the result of the fusion of two zygotes, one albino the other sable. If this was the case then Patch is a chimera. However chimeras are not the only individuals with different sets of DNAs in their bodies mosaics too have variation in their DNA.

Ferret Mosaic

A mosaic is an organism that has two or more cell populations that differ in their genetic makeup. But unlike a chimera a mosaic is not a fusion of zygotes. A mosaic starts out with the same DNA in every single cell. But at some point of its development a DNA change takes place, not in all of its cells but in some.

If this DNA change happens in the early stages of an individual's development a very large proportion of cells will be different to the rest of the cells. Assuming Patch is a mosaic but was initially destined to be a sable ferret. Something happened to the DNA in one or more cells when he was only a ball of cells - the stage between zygote and blastocyst. If only one cell lost the ability to make pigment and keeps dividing and multiplying in the end there would be millions of cells unable to make pigment forming a large white spot or patch like we see on Patch. Other cells retained the ability to make pigment creating Patch's patch of original coat colour.

Being chimera doesn't exclude being mosaic or Irish spotted as well. You could be an Irish spotted chimera or Irish spotted mosaic or chimera mosaic or Irish spotted mosaic chimera. It's all very straight forward, isn't it.

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The Stranger Within, New Scientist vol 180 issue 2421 - 15 November 2003, page 34

The Whiteness of the Ferret

What the ferret is to me and those like me I need not explain. But what it is to those unlike me needs to be explored. Why is it that ferrets can awaken emotions of dismay and even horror overpowering all reason in some humans? How can such a small creature command such power? That is what I wanted to know. I find it most difficult to concede but it may well be the once so common whiteness of the ferret above all things that is alarming. Why?

'…Though in many natural objects, whiteness refiningly enhances beauty, as if imparting some special virtue of its own, as in marbles, japonicas, and pearls; and though various nations have in some way recognised a certain royal pre-eminence in this hue;...

Though in many climes, whiteness typifies the majesty of Justice in the ermine of the Judge, and contributes to the daily state of kings and queens drawn by milk-white steeds; though even in the higher mysteries of the most august religions it has been made the symbol of the divine spotlessness and power; …the innocence of brides, the benignity of age; …yet for all these accumulated associations, with whatever is sweet, and honorable, and sublime, there yet lurks an elusive something in the innermost idea of this hue, which strikes more of panic to the soul than that redness which affrights in blood…

This elusive quality it is, which causes the thought of whiteness, when divorced from more kindly associations, and coupled with any object terrible in itself, to heighten that terror to the furthest bounds. Witness the white bear of the poles, and the white shark of the tropics; what but their smooth, flaky whiteness makes them the transcendent horrors they are? That ghastly whiteness it is which imparts such an abhorrent mildness, even more loathsome than terrific…'

MOBY DICK, by Herman Melville CHAPTER 42: THE WHITENESS OF THE WHALE

Glossary

Agouti
1. Hairs marked with alternating bands of light and dark colour and ending in a dark tip.
2. A burrowing rodent native to tropical America.

Albinism
A genetic condition marked by little or none of the pigment *melanin* in the skin, hair, and eyes.

Allele
One of the variant forms of a gene at a particular *locus* on a *chromosome***.**

Carrier
an individual that possesses a *recessive gene* whose effect is masked by a *dominant gene*; the associated trait is not apparent but can be passed on to offspring.

Choroid
A thin blood rich membrane in the eye, see *Uveal layer***.**

Chromosome
Thousands of genes are located on specialised structures called chromosomes. Every ferret cell contains 20 pairs of chromosomes.

Ciliary body
A structure in the eye, see *Uveal layer***.**

DNA
The material inside the nucleus of cells that carries genetic information. The scientific name for DNA is deoxyribonucleic acid.

Dominant gene
A version of a gene that produces a *phenotype* even when it occurs as only one of the two copies present in a cell, see: *recessive***.**

Enzyme
A protein that facilitates a specific chemical reaction.

Epistasis
Interactions between genes but not between alleles of a gene. A gene is epistatic when it influences the phenotypic expression of another gene.

Epithelium
A tissue that normally lines the surfaces and cavities of the body.

Erythrism
Red pigmentation of hair.

Erythristic
Relating to **erythrism** having reddish hair.

Eumelanin

A melanin pigment that causes shades of black or brown colouration of fur and skin.

Fovea
The central part of the *retina* that is responsible for the very best vision.

Gamete
A sperm cell or an egg cell.

Gene
A gene is the basic biological unit of heredity. It is a segment of *DNA* that codes for a particular protein.

Gene pair
The identical or non-identical alleles of a specific gene at a given *locus***.**

Genetics
The science of heredity. The study of genes, how genes produce characteristics and how the characteristics are inherited.

Genome
The complete set of genetic material for any cell.

Genotype
The genetic composition of an individual in total or at a specific *locus***.**

Germ cells
Reproductive cells, egg and sperm cells.

Heterozygote
Having two different *alleles* for a give trait.

Homozygote
An individual who has two identical *alleles* at a particular *locus,* one on each *chromosome* of a pair.

Iris
Pigmented tissue that gives colour to the eye, see: *Uveal layer.*

Loci see: **locus**

Locus (*plural* **loci)** The position on a *chromosome* that is occupied by a specific *gene.*

Meiosis
A special form of cell division to reduce the *chromosomes* within it to half the normal number. This is to ensure that fertilisation - the joining of the male *gamete* (sperm) and the female *gamete* (egg) - restores the full number of chromosomes rather than causing an abnormal number of chromosomes.

Melanin
Pigment granules in the hair and skin that give hair and skin their colour.

Melanism
The preponderance of blackness - opposite of *Albinism.*

Melanoblast
Cell that is a precursor of a melanocyte originating from the *neural crest.*

Melanocytes
Pigment-producing cells in the skin, hair and eyes that determine their colour.

Mesencephalic
Of or relating to the midbrain.

Mitosis
The process of division of somatic cells in which each daughter cell receives the same amount of DNA as the parent cell.

Mutation
Any change in the *DNA* of a cell. Mutations can be harmful, beneficial, or have no effect.

Neural Crest
Transient embryonic tissue that is replaced by the spinal cord.
Neural crest cells
Stem cells arising from the *Neural Crest*
Non-agouti
Un-banded hairs or solid colour.
Phaeomelanin
A melanin pigment that causes some shade of red, orange, gold or yellow colouration.
Phenotype
The outward appearance of an individual.
Recessive gene
A gene that only produces its affect when both copies present are identical.
Retina
The light-sensitive inner lining of the back of the eye.
Sacral
Pertaining to the sacrum the lowest part of the spine.
Semi-dominant gene
Describes a mutation which, in the *heterozygote*, produces a phenotype intermediate, but not necessarily halfway, between the *wild type* and the *homozygote.*
Somatic cell
Any cell in the body that is not a sperm or egg cell.
Stem cells
A primal undifferentiated cell from which a variety of other cells can develop through the process of cellular differentiation
Tyrosinase
Is an enzyme that catalyses the oxidation *tyrosine.*
Tyrosine
Tyrosine is also the precursor to the pigment *melanin*.
Uveal layer
Pigmented layers of the eye - iris, ciliary body and choroid.
Wild-type
The *phenotype* characteristic of the majority of individuals of a species under natural conditions.
Wild-type gene
Refers to the normal, as opposed to the mutant *gene* or *allele*.
Zygote
The fertilized egg cell.