The Color Code

by Margaret Flowers

In every issue of the ISBONA Newsletter for a number of issues, there has been a chart entitled "Coding Color & Pattern for Icelandic Sheep Registration." What's that all about? What is the big deal? How can it help me, and future generations of shepherds?

The Color/Pattern/Spotting code is, simply, a tool for identifying and recording the appearance of our sheep. Used correctly, it is also a powerful tool in checking the parentage of an animal, but also in predicting the appearance of offspring.

The basics of Color/Pattern/Spotting: The Appearance Code

I think of the appearance code something like a menu at a restaurant: You pick a salad option, an entrée option, and a dessert option. What specific option you choose for each course makes up your meal. The appearance of your sheep is made up of options of color, pattern, and spotting.

Note: The letters and numbers given below are the code "shorthand" used to indicate color/pattern/spotting of the sheep at registration. They are derived from Adelsteinsson's pioneer work on the inheritance of color and pattern in Icelandic sheep.

Color – 2 options to choose from. If you can see any color (i.e., the sheep is not white), it will be

B - black or

M - brown (moorit). Note that moorit can range from honey brown to dark chocolate.

If neither is visible (other than perhaps a small spot), the sheep is recorded as **O**

Pattern – 6 options to choose from. These are:

1 - **White** – both tog and thel are white, or might be tinged with a reddish-yellow pigment called phaeomelanin.

2 – **Gray** – the tog is black or moorit, and the thel is gray (can range from light to quite dark). Typically, there will be light circles around the eyes and "sugar lips."

3 – **Badgerface** – the tog and thel of the upper body are creamy, while the legs and underbody (chin to tail) are black or moorit. There are also characteristic badger-like facial markings.

4 – Mouflon – also sometimes referred to as “black and tan” or “reverse badgerface” - the tog and thel are black or moorit, and the underbody is a cream color – rather like a deer, elk, or moose in appearance. Also has characteristic facial markings.

5 – **Solid** – Both tog and thel are either black or moorit, and there is no evidence of any other pattern.

6 - **Gray-Mouflon** (patterns inherited together), also called the Single Gene Gray Mouflon (**SGGM**)

Now the interesting thing about these patterns is that when some of them are present simultaneously, they can both be seen. This is called “co-dominant inheritance” and applies to the gray, badgerface, mouflon and SGGM patterns. More about this later.

Spotting – 2 options to choose from. These are

S – spotted (remember: SPOTS ARE WHITE) and not spotted.

If a sheep is not spotted, there is no letter given. More about the appearance of the spots later.

What is behind all this: A quickie refresher of High School Genetics

High School? Yes, that is correct! Do you remember Mendel’s peas? Do you remember Mendel’s “Law of Segregation”, “Law of Independent Assortment”, and “Law of Dominance”? Do you remember doing Punnett Squares? This may have seemed like irrelevant “stuff” in your high school years, but it is precisely what lets us understand how the appearance traits of sheep are inherited.

First, some **definitions**.

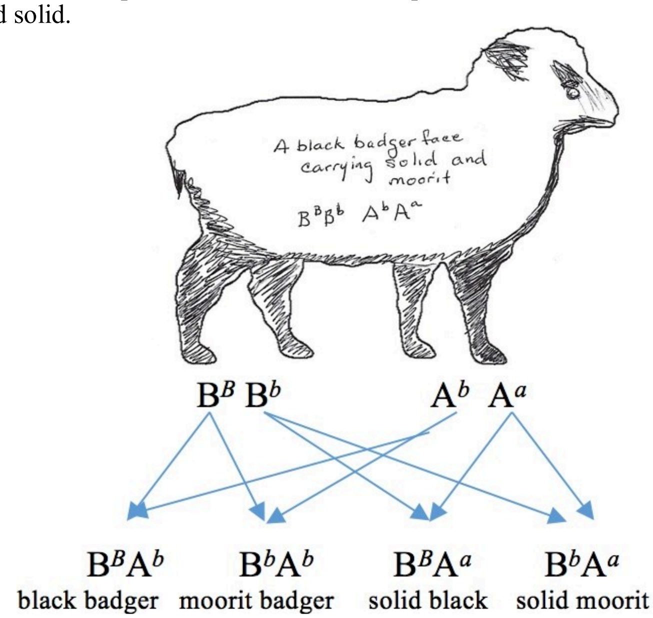
The traits we are looking at are found on specific chromosomes in the nucleus of each cell. There is a specific place, or **locus**, on the chromosome where the trait is physically located. These traits are called **genes** (designated with a capital letter, e.g., **B**). There will be two copies of the gene at each locus (one on each “arm” of the chromosome). These copies (or forms of the gene) may be identical, or they may be different. The copies are called **alleles** (designated with superscript italicized letters, e.g., $\mathbf{B}^{b}$**).**

The combination of alleles present for each trait (whether visible or not) make up the **genotype**. This is the basis or foundation of what we actually see with our eyes – called the **phenotype**. The phenotype is actual appearance of the sheep, and that is what we record when we register the sheep.

Now let’s look at **Mendel’s laws**.

The **“Law of Segregation”** states that alternate forms (alleles) of a trait (gene) are separated from one another at gamete (egg and sperm) formation (when the two arms of the chromosomes separate), and the offspring will inherit one allele from each parent. In sheep inheritance, if the color trait alleles were both black and moorit in a sheep, half the gametes would have the black allele, and the other half, the moorit. If both the alleles are the same, the trait is **“homozygous”**; if they are different, the animal is **“heterozygous”** for the trait.

The **“Law of Independent Assortment”** basically states that alleles of one trait are not linked with alleles of another trait during gamete formation. This would mean that if a sheep had alleles of black and moorit at the color locus, and badgerface and solid at the pattern locus, the gametes would be of all possible combinations in equal numbers: black and badgerface, moorit and badgerface, black and solid, and moorit and solid.



The **"Law of Dominance"** takes into account that some alleles are **"dominant"** and others **"recessive"**, that is, that when dominant and recessive alleles are both present, only the dominant one is expressed. In sheep color, if both white and solid pattern alleles are present, the sheep appears white; white is dominant over solid.

These laws apply perfectly to the Color and Spotting genes/traits. But when we look at the Pattern trait, the picture is more complex. Here we need also to consider two forms of "**non-Mendelian inheritance**". One is the situation where there are **multiple alleles**; the other is **"co-dominance."** (And yes, we are still within the bounds of high school biology.)

The Punnett Square is a useful tool to visualize and organize the progeny that are possible when a ram of known genetics is mated to a ewe of known genetics. In the simplest situation, when only one trait is examined, it will be in the following form:

	ram allele 1	*ram allele 2*
ewe allele 1	*offspring (1+1)*	*Offspring (2+1)*
ewe allele 2	*offspring (1+2)*	*Offspring (2+2)*

Dominance in the Appearance Traits.

Color – this trait shows simple Mendelian dominant/recessive expression. Black is dominant over moorit. This means that for a sheep to be moorit, both alleles must be moorit (homozygous for moorit); it had to inherit moorit from both parents as each parent contributed one color allele. In genetic shorthand, the color locus is designated "B" and the dominant allele, *B*, and the recessive allele, *b*. In the examples below, I've left off the locus designation (B) for simplicity in reading; the letters indicate the alleles present.

In a cross between a ram that is homozygous black B^BB^B and a ewe that is heterozygous for color B^BB^b , all offspring will be black, but half of them will "carry" moorit.

	B	*B*
B	*BB*	*BB*
b	*Bb*	*Bb*

They would all be registered as black.

If a cross between two sheep that were heterozygous for color were made:

	B	*b*
B	*BB*	*Bb*
b	*Bb*	*bb*

One is homozygous black, two are heterozygous, and one is homozygous moorit. Because of the complete dominance of black over moorit, the homozygous black and heterozygous sheep are indistinguishable, and would be registered as black; one of the four would be moorit and registered as such.

You might be able to determine which lambs are "carrying" moorit by doing appropriate crosses with moorit sheep. In this case, half of the offspring would be moorit, the other half heterozygous black:

	B	*b*
b	*Bb*	*bb*
b	*Bb*	*bb*

The only absolutely positive way to have 100% of the offspring be moorit, is for both parents to be moorit:

	b	*b*
b	*bb*	*bb*
b	*bb*	*bb*

Pattern - This is the most complicated trait of the three, because in it we have multiple alleles, dominant and recessive inheritance, and co-dominance all rolled into one. This pattern gene is also called the **Agouti gene**, and given the designation **A**.

Multiple alleles – as noted above, rather than the 2 alleles seen by Mendel in all his work, and as we have in the Color gene, there are 6 identifiable pattern alleles – in Icelandic sheep. Actually, there are almost 20 alleles when considering all breeds of sheep!

Dominant and recessive inheritance – This applies to the white (A^{wt}) and solid (A^{a}) alleles. White is dominant over all other patterns. If a sheep is white (more about this later), the other pattern is hidden, just as moorit is hidden under black color. Solid is recessive to all other pattern alleles; if a sheep is solid, it must be homozygous for solid pattern.

Co-dominance – Pattern alleles of gray (A^g), badgerface (A^b), mouflon (A^t) and SGGM ($A^{g\text{-}t}$) are all co-dominant.

Thus, if a sheep has alleles of gray and badgerface (A^gA^b), for example, at the pattern locus, then both are expressed, and the sheep is visually gray + badgerface. The badgerface pattern is evident, but the legs and underparts will be black-gray instead of black (or moorit-gray instead of moorit).

Similarly, gray and mouflon are co-expressed, and can be seen in a black-gray or moorit-gray back over the mouflon pattern on the legs and underparts. These gray-mouflons will look like SGGM sheep, but the gray and mouflon will segregate in the offspring, while the two patterns in the SGGM do not segregate.

Likewise, badgerface and SGGM are both expressed ($A^bA^{g\text{-}t}$),

as are badgerface and mouflon (A^bA^t).

When the gray is homozygous (A^gA^g), the animal is a very pale black-gray or moorit-gray; there is a doubling effect, which is also seen when an animal has both gray and SGGM alleles ($A^gA^{g\text{-}t}$).

This lightening of the gray is also apparent in gray-SGGM sheep ($A^gA^{g\text{-}t}$).

Note that even though there are multiple (6) alleles to choose from in Icelandic sheep, each animal has only 2 pattern alleles.

So, for example, if a gray-mouflon ram (A^gA^t) is mated to a gray-badgerface (A^gA^b) ewe, the offspring will be equal numbers of homozygous gray, gray-mouflon, gray-badgerface, and badgerface-mouflon:

	A*g*	A*t*
A*g*	A*g*A*g*	A*g*A*t*
A*b*	A*g*A*b*	A*b*A*t*

But if a white ram “carrying” gray is bred to a badger ewe “carrying” solid, half the offspring will be white (white is dominant), 1/4 will be gray badger (A^gA^b), and 1/4 will be heterozygous gray A^gA^a.

	A*wt*	A*g*
A*b*	A*wt*A*b*	A*g*A*b*
A*a*	A*wt*A*a*	A*g*A*a*

Spotting – This trait, like color, shows a pattern of complete dominance. In this case, the lack of spots is dominant S^S; spotting is recessive S^s. To display spotting, both parents must “carry” spots, one parent be spotted and the other carry spots, or both parents be spotted. Below is a cross between two sheep that “carry” spots; 1/4 of the offspring are spotted (*ss*). In the example below, I’ve left off the locus designation (S) for simplicity in reading; the letters indicate the alleles present.

	S	*s*
S	*SS*	*Ss*
s	*Ss*	*ss*

For purposes of registration, S is used to designate that spots are present (remember that they are white), and if there is no spotting observed, no letter or number is applied.

How Spotting isn't all that simple

Spots can be very small – a white blaze on the forehead, or a white foot, for example, or at the other extreme, a spot may cover almost all of the body. Spots can be particularly troublesome for determining what the sheep actually is if the spot covers critical parts of the face along with large parts of the body. It can be literally impossible to determine if an animal is gray if the muzzle and eyes are white along with a body is entirely white. In this case, it may be possible to determine the pattern of the animal by looking at the pedigree, or by the patterns expressed in the progeny.

Another issue with extensive spots is in determining whether a sheep is white (O1) or, for example, black-gray and spotted (B5S). Here also the pedigree can give an insight, or certainly the offspring.

Finally, remember that spots are white. A brilliant white. This is a "must" to remember when looking at a gray lamb. Very frequently there will be splotches of darker and lighter fleece. These are not spots, as they are not white, but a very light gray, and do not have distinct edges, which you can also see after shearing. This is not spotting, but is referred to as "flashing" and is a normal part of the gray pattern. Don't be tempted to add an "S" to the registration.

How all this fits together in the big picture.

Registering your sheep

The one part of the registration code that I have not discussed is that of horns. This is because the inheritance of horns is not completely understood. However, this does not prevent us from recording what we observe.

H – Horned. Sheep that clearly have typical horn development (sweeping back for ewes, curled forward for rams).

P - Polled. The absence of horns. There may be a depression where the horns might have been attached, or there may be a bony nub in either sex, but nothing longer.

C – Scurred. Scurs, especially in rams, can range from thin, pencil-like horny protrusions from the skull to thick curling structures of the sturdiness of true horns, but lacking the normal development, both in length and direction of growth (a favorite of these is to grow toward the eyes). Thinner than normal structures are often knocked off during head-butting games.

There are four (4) parts to the registration code: color, pattern, spotting, horns

Black vs. moorit (remember, it will be one or the other, never both, unless a rare chimera)

The pattern (or patterns) that are visible

If spotting is present, it is recorded; if no spotting, nothing is entered

The horn condition

Note: You only record what you actually observe (the phenotype). You may know the genotype, and thus the alternate allele for color, pattern, and spotting, and you may find that to be very useful information for breeding purposes, etc., but **if you can't see it, you can't report it**!

Some examples:

horned spotted black-gray mouflon ram (B24SH)

polled moorit badgerface ewe (M3P)

white horned ewe (O1H)

scurred spotted solid moorit ram (M5SC)

When should you register your sheep? There are some appearance traits that are most evident at or shortly after birth, while it may take some time for others to become evident. Patterns such as badgerface and mouflon, where there is a distinct color change are most evident in the young lamb, while the gray pattern will develop in time. This may take a couple days or even longer. Some moorit lambs are so dark at birth that they are easily mistaken for black, and in lambs with extensive spotting, it may take quite a while before the careful shepherd can be absolutely sure of the correct code to use in registration.

Also Note: The CLRC pedigree is your friend! If a color or pattern is not evident in the pedigree (don't be afraid to check the "extended pedigree"), your sheep doesn't have it. If you have what appears to be a white sheep, but there are no "O1" sheep in the pedigree, then your sheep isn't white, but spotted (a very large spot!). Look then for the "S" to appear – but remember that since this is a recessive trait, it might not appear at all.

Confirming the pedigree

Used properly and consistently, the appearance coding can be a line of defense in maintaining registry accuracy. A registered lamb cannot have an appearance code that would be impossible to produce from the sheep that are listed as the parents (except in exceedingly rare instances).

Predicting Offspring

Going back to High School biology class, you may remember a more complex Punnett Square with Mendel's peas – one that involved not just one trait, but two. This led to a very complex chart of not 4, but a maximum of 16 squares (this would be the case if both parents were heterozygous for both traits) that gave all of the possible combinations of the two traits in the offspring. Of course, just as when looking at only one trait, there may be some squares that are identical. More importantly, when patterns of dominance and co-dominance are taken into account, it is possible to predict the probability that offspring will possess a certain phenotypic combination. In our sheep, we have not 2, but 3 traits. More complexity! But still within the reach of our high school students. Here, if both parents were heterozygous for all three traits, the Punnett Square would be very large, indeed – 64 possibilities. Again, there would be some squares that would have identical genotypes, and some different genotypes would produce the same phenotype that would be registered.

So why go through this exercise? In all honesty, it is easiest to look at the color/pattern/and spotting genes individually if you want to know the possibilities that might be present in the offspring of a mating you are contemplating (or have made and are trying to guess what will pop out at lambing). Of course you need to remember the law of independent assortment in figuring out all possibilities. You would do the entire Punnett Square of 64 possibilities only if you are a fanatic about mathematical probabilities --- or you just like solving puzzles. And who doesn't like a good puzzle?

Determining genotypes from the pedigree

Example 1. Let's say you have a white ewe, and want to know what possibilities you might have in breeding her to one of your rams. Below are three generations of an actual pedigree (711662-H), with each animal given a number for ease of explanation. #1 is the ewe in question, #2 and #3 are her sire and dam, respectively, etc.

		#5 AI ram
	#2 O1H	
		#6 B4H
#1 O1H ewe		
		#7 M5H
	#3 B5SH	
		#8 B5H

Our ewe's sire (#2) is white pattern, inherited from his AI sire. We know this because white (1) is dominant over all other patterns. His dam is mouflon (4), but carries solid (5) and is likely homozygous black – these may be deduced by examining the 4th and subsequent generations. There is no record of spotting on the sire's side.

Our ewe's dam (#3) is black, solid, and spotted (B5S). Solid (5) only appears in the homozygous condition: likewise, spotting (S) is not expressed unless homozygous. Because this dam's sire (#7) is moorit, and moorit is only expressed in the homozygous condition, we know that ewe #3 must be heterozygous for color, with the black (B) masking the moorit that must have been inherited from the sire.

So what possibilities does our ewe have in breeding – what is her genotype?

Her color is not evident (O), but is there nonetheless: black inherited from the sire, and a 50% chance of moorit/50% chance of black from the dam. Her color is B^BB^B or B^BB^b

Her visible pattern is white (1), inherited from the sire; she is "carrying" solid from the dam. Her pattern genetics is $A^{wt}A^a$.

Because our ewe is white, and spots are white, there is no recorded indication of what might be present genetically. There is no evidence of spotting in the non-white sheep on her sire's side, and in Iceland for many years, the lack of spotting was actively selected for, so we are safe to say that spotting is not inherited on the sire's side. Her dam, however, is spotted, so that trait must be inherited by our ewe. So if we were able to visualize the spotting condition, we would say that our ewe was "carrying" spots; genetically S^SS^s.

Can you figure out what the lambs would be if our ewe were bred to a solid moorit spotted ram (remember all these traits must be homozygous recessive to be expressed)?

Example 2. You have a moorit mouflon ewe, and want to be **certain** to get lambs that are black mouflon. What ram should you buy?

First, you need to examine the pedigree of your ewe. While it seems that we are only concerned with two genes here – color and pattern – remember that an animal that is not showing spots might be carrying the spotting allele.

Start by locating the pedigree. Let's say it looks like this:

		#5 O1H
	#2 B5H	
		#6 B4H
#1 M4H ewe		
		#7 M5H
	#3 B4H	
		#8 B4H

From the pedigree of this ewe, we can see that she is homozygous for the recessive moorit – that's why we can see it - and must carry solid (from sire #2) in addition to the mouflon pattern. There is no evidence from these generations of the pedigree, nor from previous generations, that the spotting allele is present. We can therefore say with confidence that this ewe is B^bB^b A^tA^a S^SS^S. What would you look for in the color/pattern/spotting of a potential ram?

Now let's say that your moorit mouflon ewe has the following pedigree

		#5 O1H
	#2 O1H	
		#6 B4H
#1 M4H ewe		
		#7 M5H
	#3 B4SH	
		#8 B4H

This ewe is homozygous for moorit. She must carry spotting from the dam. What we cannot tell for certain is whether she is homozygous for mouflon (A^tA^t) or heterozygous (A^tA^a) as the mouflon allele is present in both her sire's line and her dam's line (note that the other allele must be *a* since all other patterns are either dominant or co-dominant with mouflon). So genetically she is B^bB^b A^tA^t S^SS^s **or** B^bB^b A^tA^a S^SS^s. How might the pedigree of the desired ram look different?

Answers to these examples are found on page 33

The Color Code

Answer to example #1.

Assuming the most complex situation, where the ewe is heterozygous for color:
Color: Lambs have a 50% chance of being black, 50% chance of moorit
Pattern: Lambs have a 50% chance of being white, and a 50% chance of solid
Spotting: Lambs have a 50% chance of being spotted, 50% chance of no spotting.

So, the possibilities are:
White (O1H) – 50% chance
Solid moorit (M5H) – 12.5% chance
Spotted solid moorit (M5SH – 12.5% chance
Solid black (B5H) – 12.5% chance
Spotted solid black (B5SH) – 12.5% chance

Answer to example #2.

To have the possibility of obtaining a black mouflon lamb, the only thing missing is the black color allele. The ewe could contribute mouflon, and she is not spotted. But note the **requirement** of producing a black mouflon. This lamb must be B^BB- A^tA^t S^SS- **or** B^BB - A^tA^a S^SS-.

To have certainty of a black mouflon lamb with the first ewe (B^bB^b A^tA^a S^SS^S), the ram must be homozygous black, homozygous mouflon, and could be solid or spotted (B^BB^B A^tA^t S-S-). Let's say that the one available ram is heterozygous for spotting. For simplicity, I've omitted the locus designations.

	B t S	B t s
b t S	*Bb tt SS*	*Bb tt Ss*
b a S	*Bb ta SS*	*Bb ta Ss*

All lambs from this pair are black mouflon – the desired B4H. All carry moorit, half not carry spotting, and half carry spotting. Success!

The principal difference between the first and second ewe (B^bB^b A^tA^t S^SS^s ***or*** B^bB^b A^tA^a S^SS^s), is the that the second ewe may be homozygous for mouflon, and carries spotting. For certainty in the offspring, we have to assume that she carries solid. Since spotting is not desired in the lambs, this must be taken account in the ram selection – he must be homozygous dominant (not carrying the spotting allele). So he must be (B^BB^B A^tA^t S^SS^S):

	B t S	*B t S*
b t S	*Bb tt SS*	*Bb tt SS*
b a s	*Bb ta Ss*	*Bb ta Ss*

Again, all lambs will be black mouflon (B4H). All carry moorit, half carry spotting, and half not carry spotting. More Success!