



A new integrated symmetrical table for genetic codes



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ABSTRACT

Degeneracy is a salient feature of genetic codes, because there are more codons than amino acids. The conventional table for genetic codes suffers from an inability of illustrating a symmetrical nature among genetic base codes. In fact, because the conventional wisdom avoids the question, there is little agreement as to whether the symmetrical nature actually even exists. A better understanding of symmetry and an appreciation for its essential role in the genetic code formation can improve our understanding of nature's coding processes. Thus, it is worth formulating a new integrated symmetrical table for genetic codes, which is presented in this paper. It could be very useful to understand the Nobel laureate Crick's wobble hypothesis – how one transfer ribonucleic acid can recognize two or more synonymous codons, which is an unsolved fundamental question in biological science.

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1. Introduction

The discovery of double-helix molecular structure of deoxyribonucleic acid (DNA) by [Watson and Crick \(1953\)](#) is one of landmarks in the history of science. It represents the birth of molecular biology. On the cellular level, the living organisms are classified into prokaryotes and eukaryotes. The prokaryotes are unicellular life forms while the eukaryotes include human, animal and fungus. All prokaryotic and eukaryotic cells share a common process by which information encoded by a gene is used to produce the corresponding protein. This process is called protein biosynthesis and accomplished in two steps: transcription and translation.

During transcription, DNA is transcribed into ribonucleic acid (RNA). DNA carries the genetic information, while RNA is used to synthesize proteins. DNA consists of a strand of bases, namely Adenine (A), Thymine (T), Guanine (G) and Cytosine (C), whereas RNA has A, G, C and Uracil (U) instead of T. Then, translation occurs where proteins (molecules composed of a long chain of amino acids) are built upon the codons in RNA. Each codon, which is a set of three adjoined nucleotides (triplet), specifies one amino acid or termination signal ([Crick et al., 1961](#)).

There are 20 amino acids, namely Histidine (His/H), Arginine (Arg/R), Lysine (Lys/K), Phenylalanine (Phe/F), Alanine (Ala/A), Leucine (Leu/L), Methionine (Met/M), Isoleucine (Ile/I), Tryptophan (Trp/W), Proline (Pro/P), Valine (Val/V), Cysteine (Cys/C), Glycine (Gly/G), Glutamine (Gln/Q), Asparagine (Asn/N), Serine (Ser/S), Tyrosine (Tyr/Y), Threonine (Thr/T), Aspartic acid (Asp/D) and Glu-

tamic acid (Glu/E). For the formation of proteins in living organism cells, it is found that each amino acid can be specified by either a minimum of one codon or up to a maximum of six possible codons. In other words, different codons specify the different number of amino acids. A table for genetic codes is a representation of translation for illustrating the different amino acids with their respectively specifying codons, that is, a set of rules by which information encoded in genetic material (RNA sequences) is translated into proteins (amino acid sequences) by living cells. There are a total of 64 possible codons, but there are only 20 amino acids specified by them. Therefore, degeneracy is a salient feature of genetic codes. Genetic information is stored in DNA in the form of sequences of nucleotides which is made clearly in the double-helix model, but it does not provide any clue on how one transfer ribonucleic acid (tRNA) can recognize two or more synonymous codons. Therefore, deciphering the genetic codes becomes a problem. Up to now, it is still unable to find out the reason or explanation for these kinds of characteristics and relationships between codons and amino acids. Therefore, it has always been an interesting area for us to explore and obtain any explanation further.

The table for genetic codes allows us to identify a codon and the individual amino acid assigned to the codon by nature. These assignment tables may come in a variety of forms, but they all suffer from an inability of illustrating a symmetrical nature among genetic base codes. In fact, because the conventional wisdom avoids the question, there is little agreement as to whether the symmetrical nature actually even exists. A better understanding of symmetry and an appreciation for its essential role in the genetic code formation can improve our understanding of nature's coding processes.

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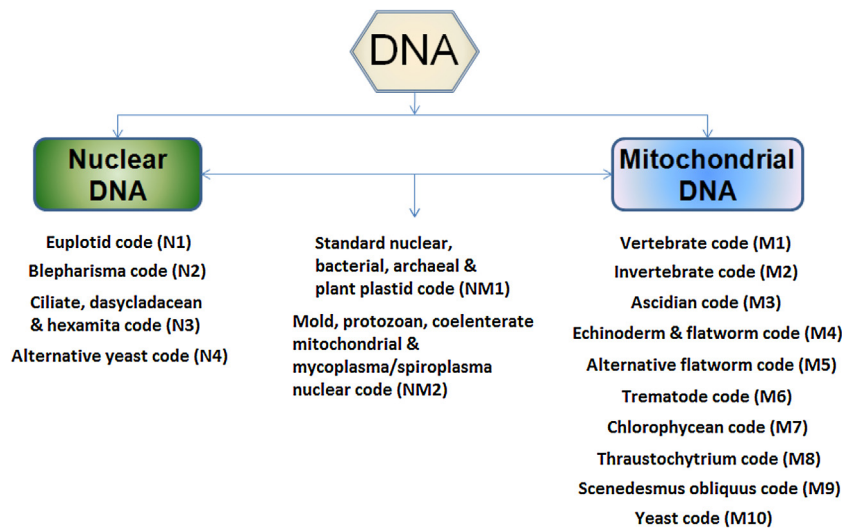


Fig. 1. Genetic codes.

Thus, it is worth formulating a new integrated symmetrical table for genetic codes.

2. Genetic codes

The genetic codes for translation can be categorized into two main categories: nuclear and mitochondrial codes, which are the genetic codes of nuclear deoxyribonucleic acid (nDNA) and mitochondrial deoxyribonucleic acid (mtDNA) respectively. Each category has various different genetic codes for the translation of a particular class, genus or species of living organisms. Not all organisms can use standard nuclear code for translation and some organisms of the same family can have the different set of translation codes. As shown in Fig. 1, there are total 16 genetic codes, that is, standard nuclear, bacterial, archaeal & plant plastid code (NM1) (Nirenberg and Matthaei, 1961), mold, protozoan, coelenterate mitochondrial & *mycoplasma/spiroplasma* nuclear code (NM2) (Fox, 1987), euplotid nuclear code (N1) (Hoffman et al., 1995), *blepharisma* nuclear code (N2) (Liang and Heckmann, 1993), ciliate, dasycladacean & *hexamita* nuclear code (N3) (Schneider et al., 1989), alternative yeast nuclear code (N4) (Ohama et al., 1993), vertebrate mitochondrial code (M1) (Barrell et al., 1979), invertebrate mitochondrial code (M2) (Batuecas et al., 1988), ascidian mitochondrial code (M3) (Yokobori et al., 1993), echinoderm & flatworm mitochondrial code (M4) (Himeno et al., 1987), alternative flatworm mitochondrial code (M5) (Bessho et al., 1992), trematode mitochondrial code (M6) (Garey and Wolstenholme, 1989), chlorophycean mitochondrial code (M7) (Hayashi-Ishimaru et al., 1996), *thraustochytrium* mitochondrial code (M8) (Goldstein, 1973), *scenedesmus obliquus* mitochondrial code (M9) (Nedelcu et al., 2000) and yeast mitochondrial code (M10) (Clark-Walker and Weiller, 1994).

3. Symmetrical genetic codes

In standard nuclear code (Nirenberg and Matthaei, 1961), the arrangement of amino acid assignment is not random, presumably as the product of evolution to enhance stability in the face of mutation (Freeland and Hurst, 1998; Freeland et al., 2000, 2003; Sella and Ardell 2006), tRNA misloading (Yang, 2004; Jestin and Soulé, 2007; Seligmann, 2010b, 2011, 2012), frame shift (Seligmann and Pollock, 2004; Itzkovitz and Alon, 2007; Seligmann, 2007, 2010a) and protein misfolding (Guilloux and Jestin, 2012). As shown in Fig. 2(a), the original genetic code is arranged in the conventional form

		2nd Position				
		U	C	A	G	
1st Position	U	F	S	Y	C	U
		F	S	Y	C	C
		L	S	*	*	A
		L	S	*	W	G
	C	L	P	H	R	U
		L	P	H	R	C
		L	P	Q	R	A
		L	P	Q	R	G
	A	I	T	N	S	U
		I	T	N	S	C
		I	T	K	R	A
		M	T	K	R	G
G	V	A	D	G	U	
	V	A	D	G	C	
	V	A	E	G	A	
	V	A	E	G	G	

		3rd Position				
		C	A	G	U	
1st Position	C	P	P	P	P	C
		H	Q	Q	H	A
		R	R	R	R	G
		L	L	L	L	U
	A	T	T	T	T	C
		N	K	K	N	A
		S	R	R	S	G
		I	I	M	I	U
	U	S	S	S	S	C
		Y	*	*	Y	A
		C	*	W	C	G
		F	L	L	F	U
G	A	A	A	A	C	
	D	E	E	D	A	
	G	G	G	G	G	
	V	V	V	V	U	

(a) original table

(b) symmetrical table

Fig. 2. Standard nuclear code.

following the mapping sequence from left to right. The appearance of degeneracy in the conventional table implies the existence of certain symmetry for codon multiplicity assignment (Findley et al., 1982; Shcherbak, 1988; Bashford et al., 1998; Hornos et al., 2004; Nikolajewa et al., 2006; Gavish et al., 2007; Rosandić and Paar, 2014). Fig. 2(b) shows another way of arrangement of standard nuclear code by changing sequence position from “1-2-3” to “1-3-2” and base sequence at each position from “U-C-A-G” to “C-A-G-U”. This is different from the conventional table of standard nuclear code. A newly-formulated genetic code presents a new perspective of genetic code.

From Fig. 2(b), it shows that the rearranged standard nuclear code exhibits a symmetrical pattern along the vertical centerline except that the 4 codons (UGA||UGG and AUA||AUG) at the center of table are not symmetrical to each other.

Although the 4 codons are not perfectly mirrored about the vertical centerline, it is still possible to see the pairing characteristics

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