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Review

Physiological concentrations of purines and pyrimidines

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Abstract

The concentrations of bases, nucleosides, and nucleosides mono-, di- and tri-phosphate are compared for about 600 published values. The data are predominantly from mammalian cells and fluids. For the most important ribonucleotides, average concentrations ± SD (μM) are: ATP, 3,152 ± 1,698; GTP, 468 ± 224; UTP, 567 ± 460 and CTP, 278 ± 242. For deoxynucleosides-triphosphate (dNTP), the concentrations in dividing cells are: dATP, 24 ± 22; dGTP, 5.2 ± 4.5; dCTP, 29 ± 19 and dTTP 37 ± 30. By comparison, dUTP is usually about 0.2 μM. For the 4 dNTPs, tumor cells have concentrations of 6–11 fold over normal cells, and for the 4 NTPs, tumor cells also have concentrations 1.2–5 fold over the normal cells. By comparison, the concentrations of NTPs are significantly lower in various types of blood cells. The average concentration of bases and nucleosides in plasma and other extracellular fluids is generally in the range of 0.4–6 μM; these values are usually lower than corresponding intracellular concentrations. For phosphate compounds, average cellular concentrations are: P_i, 4400; ribose-1-P, 55; ribose-5-P, 70 and P-ribose-PP, 9.0. The metal ion magnesium, important for coordinating phosphates in nucleotides, has values (mM) of: free Mg^{2+}, 1.1; complexed-Mg, 8.0. Consideration of experiments on the intracellular compartmentation of nucleotides shows support for this process between the cytoplasm and mitochondria, but not between the cytoplasm and the nucleus. (Mol Cell Biochem **140**: 1–22, 1994)

Key words: purines, pyrimidines, nucleosides, nucleotides

Introduction

Nucleotides serve two major types of functions in the cell. As NTPs or dNTPs they are the immediate building blocks for the many RNAs and DNA. And as NTPs they also serve as co-substrates in the activation of many metabolites, such as UDP-sugards, CDP-choline, or AMP-amino acids, to give only a few examples. ATP is especially important as the most commonly used phosphate donor for about 200 different kinases, and therefore is the most abundant nucleotide. GTP is becoming increasingly more recognized in special pathways of intracellular signaling, involving G-proteins, which undergo slow conformational change on hydrolyzing GTP to GDP. Such diverse functions have led to the need for nearly constant pools of nucleotides, which can be replenished by *de novo* pathways for the synthesis of either IMP or UMP, as well as by salvage pathways that can convert available bases or nucleosides to the respective NMP or dNMP. Considering only the different bases, nucleosides, and nucleotides, there are 50 of these compounds in the various purine and pyrimidine pathways (Fig. 1). There are over 70 different enzymes in purine and pyrimidine metabolism, and enzymes using such compounds have received considerable attention; the physical and ligand binding properties of these enzymes were recently reviewed [1].

A knowledge of the actual cellular concentration of these metabolites has always been important to studies focused on pharmacology, to aid in strategies for using analogs which will compete with the natural compounds *in vivo*. Such data are also important in characterizing the enzymes in this field,

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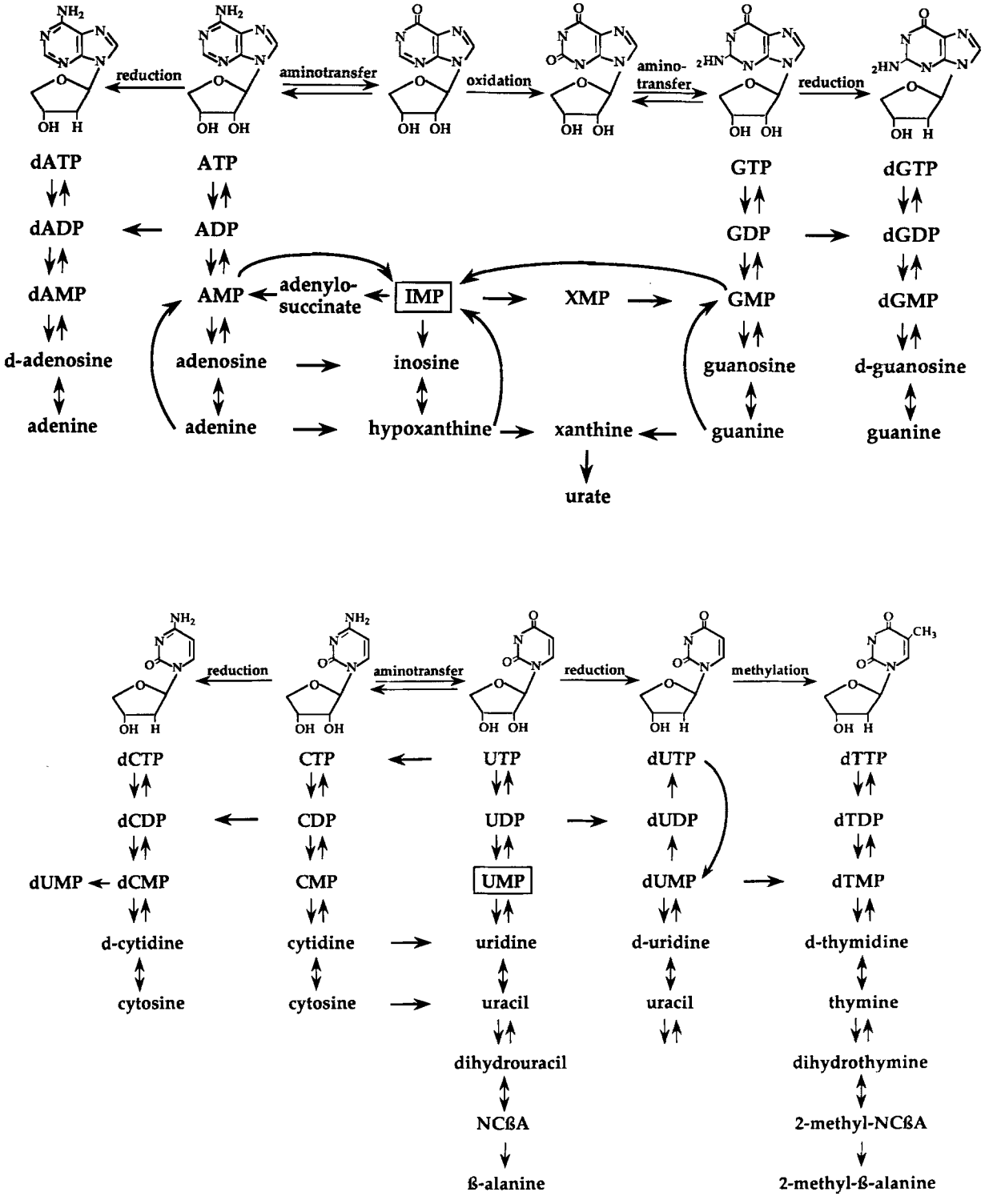

Fig. 1. Compounds in purine and pyrimidine metabolism. Modifications of the purine base, or of the ribose, are represented horizontally, changes in phosphorylation, nucleoside cleavage, or catabolism of the base are represented vertically. Each arrow represents a distinct enzyme activity. *Upper panel*: purine metabolism; the boxed nucleotide, IMP, is the product of the *de novo* pathway. *Lower panel*: pyrimidine metabolism; the boxed nucleotide, UMP, is the product of the *de novo* pathway. NCβA = N-carbamoyl-β-alanine.

so that kinetic studies defining the affinity of enzymes for substrates or regulatory ligands can be related to the actual physiological concentration of the same ligands.

The data base

An effort was made to find representative data for all compounds from human sources. Otherwise, the present data set largely reflects the increasing work of the last 15 years, and partly reflects a bias due to the interest of workers in the field: the data are overwhelmingly from mammalian systems, with rodents and humans being most frequently included. Concentrations for metabolites in fluids are routinely reported in μM units, but values determined for cell or tissue samples were more commonly reported as 'nmoles/g wet weight' or 'nmoles/10^9 cells'. For data of the latter type, such values were converted to μM units, for ease of comparison, by using the values for total cell volumes and for the intracellular volume or fluid volume (Table 7). When no specific value for cell volume was available for a particular case, then the calculation was made using the average value, based on the data in Table 7, of 2.6 ml/10^9 cells. Since intracellular fluid volumes are more consistent, except for erythrocytes, a value of 0.8 ml/g tissue was always used. Therefore the calculated 'μM value' is sometimes only a good estimate. The complete tabulation of about 600 values are listed in Table 8.

It is often desirable to know the concentration of a ligand that is free, or the value of such a concentration in a particular subcellular compartment. Such data are largely unavailable for most compounds. The present data set generally presents total concentrations for most of the ligands included. The problem of compartmentation has also not received wide attention. The present values are generally for whole cells or tissues, but still serve as a very useful first estimate for any given ligand concentration in any compartment.

Multiple entries occur frequently in Table 8 for the same compound from the same source. This could not be avoided, since there was no consistent way to judge one of the reported values as being most correct. This also permits an appreciation of the normal variability for such data, which may be due to variation in the measuring technique, or in the state of the tissue sample, so that significant variations in the concentration range of a single compound are frequently seen. As shown in Table 8, for a given compound from different sources a variation in the concentration of 100 fold is not uncommon, and there are examples in Table 8 showing a >10,000 fold range (hypoxanthine), and a >1000 fold range (IMP). Table 1 shows average concentration values for each compound listed in Table 8. Because they frequently deviated from the mean, concentration values from blood forming cells were not used to calculate values for Table 1. Also, whenever one of the values for a particular compound deviated by ≥ 1 order of magnitude from the average, such outliers were not included in computing the average concentration.

Average concentrations of purines and pyrimidines

Such values, across all examples for any given compound, are shown in Table 1. Due to increased interest related to medicine, values for humans are shown separately, and average values for all other species combined are shown under 'general'. Compounds in the *de novo* pathways, or catabolic pathways are generally omitted due to insufficient data. For the 'general' values, standard deviations are also given when there were enough sample values for this calculation. This standard deviation gives an immediate appreciation for the scatter of reported values. Such variation in the observed concentration for the same compound may be due to true variation between tissues in the same organism, or between species. In part, it also reflects different experimental approaches.

When looking thoroughly through Table 1, it becomes evident that in the great majority of cases, the average concentration of a compound is lower in humans than in other organisms. Two factors may have contributed to this being a skewed representation. Data for human samples come largely from blood cells (for the nucleotides), or from extracellular fluids (for bases and nucleosides). As this will be described below, extracellular fluids usually have lower concentrations of a given compound than cells. As the data show, blood cells are somewhat below average in their nucleotide content. Thus, human values may be skewed downwards. Secondly, the non-human data include many examples of tumor cells, which often have above average concentrations of nucleotides (described below).

For bases and nucleosides, concentrations are generally in the range of 0.4–6 μM, with a few very obvious exceptions. Among the purines, hypoxanthine and inosine are significantly higher. This may reflect the fact that inosine and hypoxanthine have dual roles. They are intermediates in the catabolism of IMP, AMP and GMP (Fig. 1). Also, since purines are salvaged by a phosphoribosyltransferase reaction, inosine and hypoxanthine are also biosynthetic compounds. The value for guanine in humans represents a single value which may be unusual. For the pyrimidines, orotidine is unusually high, and this may reflect unusual values in a small data set, with only 2 values for humans, and a single value from a mouse tumor (in the 'general' column). Since orotidine is not itself in the biosynthetic or salvage pathway, such a high value signifies an accumulation of OMP, which is then available to a nucleotidase. Normally such orotidine is converted back to orotate by an enzyme such as uridine phosphorylase [2]. In Ehrlich ascites cells pyrimidine biosynthesis *de novo* functions efficiently so that orotidine is barely

Table 1. Average concentrations of purines and pyrimidines

	Concentration (μM)			Concentration (μM)	
Purine compound	Human	General	Pyrimidine compound	Human	General
adenine	0.4	2.7 ± 2.2	cytosine	*1.5*	*6.4* ± 8.5
adenosine	0.5	3.1 ± 2.2	cytidine	*0.6*	*4.7* ± 2.7
AMP	82	209 ± 176	CMP	67	34 ± 19
ADP	137	849 ± 367	CDP	0.8	71 ± 51
ATP	2,102	3,152 ± 1,698	CTP	91	278 ± 243
guanine	97	*0.4*	uracil	*1.3*	*5.8* ± 8.3
guanosine	*0.9*	*4.5* ± 2.9	uridine	*5.2*	10.4 ± 8.7
GMP	32	64 ± 39	UMP		184 ± 127
GDP	36	159 ± 51	UDP	3.5	155 ± 113
GTP	305	468 ± 224	UTP	253	567 ± 460
hypoxanthine	172	570 ± 483	orotate	<5	0.4
inosine	168	5.0 ± 6.3	orotidine	13	149
IMP	23	63 ± 41	OMP		8.0
xanthine	20	25	thymine		*2.4*
			deoxythymidine	*0.5*	*4.9* ± 5.2
XMP	7.3	3.8	dTMP	1.4	0.5
			dTDP	2.4	1.5
			dTTP	17	37 ± 30
			deoxycytidine	*0.7*	*14*
dAMP		21	dCMP	1.9	0.3
			dCDP	0.1	1.0
dATP	2.4	24 ± 22	dCTP	4.5	29 ± 19
			deoxyuridine	*0.6*	0.6
dGMP		9.1	dUMP	2.7	2.2
			dUDP	0.5	0.1
dGTP	2.7	5.2 ± 4.5	dUTP	0.7	0.2 ± 0.2

Values in italics were determined soleley in extracellular fluids.

detectable [2]; therefore the values of orotidine in Table 1 imply an inefficient phosphorylase activity, or a block at the OMP decarboxylase step. In addition, a circadian rhythm may influence such data, since it has been demonstrated that uridine phosphorylase varies by four fold in mice over 24 h [3]. Both uridine and deoxycytidine are also at slightly higher concentrations, and for uridine this is due to intracellular accumulation (see below).

For the nucleotides there is a consistent pattern of (d)NTP >(d)NDP>(d)NMP, with the striking exception of deoxyuridine nucleotides. Since dUMP is the immediate precursor for dTMP, its concentration is normal and comparable to dCMP or dTMP. However, dUDP and especially dUTP are dramatically low, due to the action ofUTPase [4], which replenishes dUMP (Fig. 1). This is seen as desirable to minimize the availability of dUTP for misincorporation into DNA. The NTPs, as the functional nucleotides in metabolism, are the most abundant, with concentrations (μM) of: ATP, 3152; GTP, 468; UTP, 567; and CTP, 278. For the NXPs, there is an approximate pattern of increasing concentrations (relative to the NMP) with NDPs at two to four fold, and NTPs at 8–15 fold. A little inconsistent with this pattern are the UXPs, where UMP appears at a more elevated level, so that UDP is at an equivalent concentration, and UTP at less than four fold.

Bases and nucleosides: extracellular vs intracellular

The ready availability of extracellular bases and nucleosides for salvage pathways has long been a subject for studies on their uptake or transport into cells (e.g. [5, 6]). However, such transport studies could not examine all the possible compounds, and the data in Table 2 compare the available information regarding established concentrations in the two environments. On the assumption that these metabolites exchange readily between most fluid compartments, such data have been grouped together in Table 2, although the great majority of data was determined for plasma or serum samples. In general, the concentration of a given base is

Table 2. Average concentrations of bases and nucleosides in extracellular fluids and cells

Compound	Concentration (μM) ± SD		Reference
	Extracellular	Intracellular	
adenine	4.4 ± 2.6	1.5 ± 1.1	21–26
adenosine	3.2 ± 2.9	1.8 ± 1.4	23–29
cytosine	6.4 ± 8.5		25, 27, 30, 31
cytidine	4.1 ± 2.9		25, 27, 30–35
deoxycytidine	12.1 ± 14.6		22, 25, 31, 35
guanine	0.4	97	25, 36
guanosine	4.5 ± 2.9	7.1	25, 27, 37
hypoxanthine	2.8 ± 1.6	570 ± 483	21, 23, 25, 26, 29, 35, 38–42
inosine	4.0 ± 6.2	211 ± 28	23, 25, 26, 27, 29, 35, 37, 39, 40–45
orotate	0.1	62	8, 46–49
orotidine	5.0	85	8, 50
thymine	2.4		25, 27
deoxythymidine	4.0 ± 4.9		22, 25, 27, 35, 51–53
uracil	4.3 ± 7.1		21, 25, 27, 31, 54
uridine	5.3 ± 4.2	15.4 ± 10	22, 25, 30–35, 37, 40, 41, 43, 45, 54–61
deoxyuridine	0.6 ± 0.3		22, 35, 62

comparable to the respective nucleoside (except for orotate and orotidine) found in extracellular fluids.

When intracellular values are compared to those in extracellular fluid where such data are available, there is general support for some accumulation of bases and nucleosides inside the cell. The clear exceptions are for adenine and adenosine, perhaps reflecting the much greater utilization of adenine nucleotides, so that their precursors do not accumulate in the cell. The most significant intracellular accumulation occurs for guanine, hypoxanthine, and inosine, as well as for orotate and orotidine. The fact that plasma concentrations of bases and nucleosides are generally in the low micromolar range may reflect that active uptake of these compounds is effective and widespread. It is also worth noting that these compounds, especially the bases, have poor solubility, and that the observed concentrations are also consistent with this feature.

(d)NTPs: normal vs. tumor cells

Many researchers have investigated the increase in nucleotides in normal cells or in tumor cells, leading to an appreciation that dNTP levels are generally elevated in actively dividing cells. As shown in Table 3, dNTPs are uniformly at low micromolar concentrations in normal resting cells, and undergo an increase of nearly five to ten fold in dividing tumor cells. However, while dATP, dCTP and dTTP are again at comparable concentrations in tumor cells, dGTP is not as elevated. This discrepancy may simply be a function of the limited data available. Equally important is the expansion of the NTP pools to facilitate mitosis. Even ATP, already the most abundant nucleotide, appears to undergo a further average increase of about 25%. The most significant relative increase is for CTP, but this also reflects the low concentration of this nucleotide in non-mitotic cells. For the dNTPs, note that the variability in the published values (±SD) is usually equal to the average concentration for that compound. This reflects the difficulty in obtaining such data, and the variability that may come from different experimental methods. While the NTPs are usually at concentrations 100–1000 fold higher than their respective dNTPs, the variability in such data remains almost as high!

The fact that nucleotide pools are generally elevated in tumor cells probably contributes to the differences in Table 1 between 'human' and 'general' values, since only the latter consistently include data from tumor samples. Nevertheless, the values in Table 1 under 'general' should not be lowered to compensate for this. An additional problem in measuring nucleotides, especially triphosphates, is the lability of the terminal phosphate, either due to chemical hydrolysis in the extracting buffer, or due to endogenous phosphatases that become liberated during cell fractionation. This may lead to underestimating the true intracellular concentrations. Many reports have focused on improving techniques to extract nucleotides from isolated cells or tissues (e.g. [7, 8]), but it appears that whether the sample is from tissue or free cells is

Table 3. Concentrations of nucleoside triphosphates in normal vs. tumor cells

Nucleotide	Concentration (μM) ± SD		Tumor/ normal	Reference
	Normal	Tumor		
dATP	3.2 ± 3.4	23 ± 22	7.2	7, 63–68
dGTP	1.5 ± 1.0	7.2 ± 4.4	4.8	7, 63–68
dTTP	5.4 ± 6.4	32 ± 24	5.9	7, 23, 62–66, 68–74
dCTP	2.1 ± 2.7	29 ± 20	13.8	7, 62–66, 68, 69, 74
ATP	2,537 ± 1,217	3,134 ± 2,135	1.2	8, 23, 24, 42, 48, 63, 64, 67, 73–89
GTP	232 ± 202	473 ± 214	2.0	8, 23, 24, 42, 47, 48, 63, 64, 73, 77, 79, 82–91
UTP	227 ± 321	686 ± 542	3.0	8, 24, 37, 47, 63, 64, 67, 76, 77, 79, 82–89, 92
CTP	83 ± 133	402 ± 252	4.8	8, 47, 63, 64, 67, 69, 76, 77, 79, 82, 83–87, 89, 92

Table 4. Concentrations of nucleotides in tissues vs. cultured cells

	Concentration (μM) ± SD		
Nucleotide	Tissues	Normal cells	Tumor cells
ATP	3,533 ± 795	2,537 ± 1,217	3,134 ± 2,135
GTP	469 ± 227	232 ± 202	473 ± 214
UTP	367 ± 84	227 ± 230	686 ± 542
CTP	92 ± 34	83 ± 133	402 ± 252

not itself a factor that should bias the experimental result. This interpretation is evident in Table 4, where the same data shown in Table 3 are summarized by different criteria.

In Table 4, free cells (or cell cultures) are separated into normal cells (lower mitotic rate) and tumor cells, and compared to all tissues (normal + tumor, though tissues are mostly normal). For the concentration of ATP and GTP there is no significant difference for tissues compared to tumor cells, but the values of these nucleotides in normal cells are significantly lower. This suggests that the structural state of the cell is not responsible for any variation in extraction of nucleotides, but that normal (resting) cells simply have a lower concentration of nucleotides. This is consistent with the increased demand for nucleotides in mitosis. However, for UTP and CTP, tumor cells have distinctly greater concentrations than found in tissues, and again normal cells have the lowest concentrations. The increase in the pyrimidine nucleotides for tumor cells may reflect the need to elevate pyrimidine pools, which are normally lower than purine pools, since DNA synthesis requires a more balanced quantity of the four nucleotides.

The above description emphasizes the extent of variability, and suggests at least one immediate factor to account for such variability: whether cells or mitotic or quiescent. The second important source of variability must be the experimental technique, since for the same cell line or tissue, reported concentrations of a particular nucleotide varying by 5–50 fold are not unusual. As examples: AMP in human lymphocytes, deoxycytidine in rat plasma, CMP in rat liver, GRP in human lymphocytes, IMP in human erythrocytes, or UMP in rat liver (see Table 8). While special types of cells may have physiologically necessary deviations in their nucleotide content, related to unique functions of the cells, or a special developmental phase of the cells, the average concentrations shown in Tables 3 and 4 may generally be safer estimates for such values.

Studies on compartmentation

This topic has become quite controversial, and an earlier review presents a thorough discussion of the technical difficulties of such studies, and of some possible ambiguities in data interpretation [9]. Most studies measuring cellular nucleotides and their metabolites have not made an effort to measure the actual concentration of these compounds in separate cellular compartments. Mainly adenine and guanine nucleotides, as well as dNTPs have been examined for compartmentation. Experiments discussed in that earlier review [9] and in a second review [10] show little conclusive support for compartmentation between the cytoplasm and nucleus, although compartmentation of nucleotides between cytoplasm and mitochondria is more strongly supported. These will be considered separately.

1. Compartmentation between cytoplasm and nucleus

As detailed in two earlier reviews [9, 10], compartmentation between cytoplasm and nuclei has not been consistently observed. One physical difficulty to maintaining separate pools is that the pore size of the nuclear envelope is about 10 nm, and even macromolecules (e.g. many enzymes) freely equilibrate between these two compartments [10], so that the nuclear membrane may not present an effective barrier for small metabolites. Compartmentation studies generally follow the uptake of a radioactive nucleoside or base, while also manipulating the corresponding nucleotide pool, either by inhibiting *de novo* or salvage pathways (with specific inhibitors), or by expanding that nucleotide pool (by growth in the presence of the unlabeled nucleoside). In interpreting the subsequent results, two points are generally not considered: 1) the absolute size of the appropriate nucleotide pool under control and under experimental conditions; and 2) the difference in existing enzymatic rates for incorporating different nucleosides or bases into the chosen nucleotide pool. Examples will illustrate these difficulties.

a. Importance of nucleotide pool size. One study claimed evidence for the separation of *de novo* and salvage thymidine nucleotide pools [11]. Using HeLa cells, the incorporation of [^{3}H]thymidine into DNA was measured in control cells (grown in minimal medium) and in cells that had been grown in HAT medium (hypoxanthine, aminopterin, thymidine). Samples taken after the addition of [^{3}H]thymidine showed only a 1 min lag before it was steadily incorporated into DNA for control cells, and about a 6–7 min lag for cells grown in HAT. The authors concluded that the more rapid uptake in the control cells showed that the [^{3}H]thymidine being incorporated completely bypassed the *de novo* thymidine nucleotide pools [11]. However, as shown in Table 1, dTTP pools are normally small, and the turnover time is rapid under conditions of DNA synthesis [12], which permits rapid equilibration of exogenous [^{3}H]thymidine. When these cells were grown in HAT, the dTTP pools may have expanded four to five fold (such expansion of the much greater UXP pools has been measured for cells grown on uridine [13, 14], or on orotate [14]), and this would necessitate a greater time for

exogenous [^{3}H]thymidine to equilibrate into the dTTP pool before showing steady incorporation into DNA. Thus, simple expansion of a single dTTP pool may account for the increased lag time observed in this experiment when cells were grown in HAT.

b. Importance of different rates for salvage and de novo *pathways.* Using rat hepatocytes, a recent study measured uptake of [^{14}C]orotate (at 61 mCi/mmol) and [^{3}H]cytidine (at 29 Ci/mmol) into isolated nucleotides and RNA [14]. By observing different ratios of ^{14}C/^{3}H in such endproducts, the authors concluded that these cells contain 3 distinguishable pools of UTP. The authors showed that the incorporation of [^{14}C]orotate into UTP and other endproducts had a rate >100 times the rate for incorporation of [^{3}H]cytidine into its endproducts. This reflects the difference in the intrinsic activities for the initial enzymatic reactions (orotate → UMP, and cytidine → CMP) since the same enzymes are involved for subsequent steps with either precursor. For control cells, a 1 h labeling time with both precursors leads to ^{14}C/^{3}H greater than two for UXP pools (no correction was made for the large difference in specific radioactivity of the two precursors that favors ^{3}H). The same experiment showed ^{14}C/^{3}H less than 0.05 for CXP pools. Although cytidine is phosphorylated slowly, it is still more effective than orotate at labeling CTP, since for orotate the liming step now is the conversion of UTP to CTP, since CTP synthetase also has a very modest activity. However, this study found that when hepatocytes are first incubated for 16 h with an unlabeled precursor, this led to significant expansion of the UTP pool (generally three to six fold) and a modest expansion of the CTP pool (1.3–1.8 fold). After such treatment, [^{3}H]cytidine was much less effective at labeling endproducts, while the incorporation of orotate was unchanged, and led to the proposal for multiple UXP or CXP pools. However, this treatment to increase total UTP and CTP pools would also lead to a significant decrease in the activity of uridine-cytidine kinase by feedback inhibition [15], so that the processing of cytidine into CTP would be diminished. In contrast, the data in this study show no feedback inhibition on utilization of orotate when the NTP pools were expanded. Thus, consideration of the different rates for salvage and *de novo* pathways, plus the feedback-inhibition effecs of expanded UTP and CTP pools can also account for the observed ^{14}C/^{3}H ratios.

The above emphasizes the importance of measuring actual metabolite concentrations, and of considering the actual rates of different metabolic pathways. For direct measurements of adenine nucleotides and UTP no differences were observed for concentrations of such nucleotides derived from whole tissue, or from isolated nuclei [16]. While compartmentation between cytoplasm and nucleus may occur under some conditions, currently available data are not conclusive in support of this, and the metabolite concentrations determined for whole cells (Table 1) may be used as a good estimate for such compounds in the nucleus.

2. Compartmentation between cytoplasm and mitochondria

There is a better consensus on compartmentation between these two locales, suggesting that the mitochondrial membrane acts as a more effective barrier. However, results are not consistent as to which compartment has the higher ATP/ADP ratio (reviewed in [9]). Adenine nucleotides have generally been measured, and show higher concentrations in the mitochondrion when studied in perfused liver [17], or in isolated hepatocytes [18, 19]. These values are shown in Table 5. Although there are only limited data for these subcellular compartments, it is worth noting that the average concentrations for adenine nucleotides (Table 1) are good estimates for the cytoplasmic concentrations shown in Table 5, but not for the mitochondria.

Table 5. Adenine nucleotide concentrations in cytoplasm and mitochondria

	Concentration (mM) ± SD		
Compartment	ATP	ADP	AMP
Cytoplasm	3.3 ± 0.5	0.7 ± 0.6	0.4 ± 0.4
Mitochondrion	8.0 ± 2.6	6.0 ± 1.7	2.9 ± 2.0

Concentrations of phosphate compounds

For purines as well as pyrimidines, both *de novo* and salvage pathways require P-ribose-PP, and this important metabolite is directly formed from ribose-5-P. Concentrations of P_i and all ribose-phosphate compounds are in Table 6. P-ribose-PP concentrations are at fairly similar concentrations in lymphocytes from different mammals, but are more elevated in other tissues in a range of 5–16 μM, and appear to be considerably elevated in porcine fibroblasts. On average, the concentrations of both ribose-1-P and ribose-5-P are generally five to ten fold higher than P-ribose-PP. For all the phospho-pentose compounds, the standard deviations shown in Table 6 illustrate again the significant variation reported for such measurements. The average for all values of inorganic phosphate is at about 4.4 mM, while the concentrations of free Mg^{2+} are about 0.85 mM. The bulk of the cell's magnesium pool is complexed to various compounds, with a total concentration of 8 mM.

Cell volumes

Necessary to the calculations shown in Tables 1–4 is a value for the intracellular, or fluid volume of the cell in which the

Table 6. Concentrations of phosphate and phospho-pentoses

Compound (source)	Concentration ± SD (μM)	Reference
P_i		
human lymphocytes	2,770	48
mouse cells	5,250	18, 93
Ribose-1-P		
mouse cells	49 ± 42	94, 95
rat cells	64 ± 42	94
Ribose-5-P		
human lymphoblasts	70	48
P-Ribose-PP		
mammalian lymphocytes	2.5 ± 0.5	48, 96
mouse tissues	13.7 ± 4.9	97
porcine fibroblasts A9P	373	98
Mg^{2+} (free)		
human serum	1,430	99
rat brain	445	44
mouse Ehrlich ascites:		
(free Mg^{2+})	400	100
(bound-Mg)	8,000	100

various compounds are located. Values for 14 different cell types are listed in Table 7. Excluding erythrocytes which are uniquely small because of their special function, the other cell types show a volume range of less than five fold. The average value for this data set (excluding erythrocytes) is 2.56 ± 1.3 ml/10^9 cells, and this value was used for those cells where specific information was unavailable. Intracellular volumes are for the available fluid space. For the limited data set, these values do not show much variability. Again, erythrocytes have the lowest value. Note that the value of 0.1 ml/10^9 cells for erythrocytes indicates that these cells are small, while the value of 0.7 ml intracellular volume per gram erythrocytes indicates that for these cells, their cytoplasm is more densely packed.

Using concentration values

When enzymes are characterized for their affinity towards physiological ligands (measured as K_m or K_i), it is relevant to compare such affinity constants to the known physiological concentration of the specific ligand. Such affinity constants are most commonly comparable to, or significantly lower than the cellular concentration of that ligand. Such a relationship is consistent with the expectation that the enzyme may be partly or extensively bound with the ligand *in vivo*, especially when this is a substrate. When the affinity constant measured is significantly poorer than the physiological concentration of the ligand, this is often diagnostic that the isolated enzyme is not completely in its normal native state. Since the procedures used to purify enzymes may cause some degree of enzyme denaturation, such a comparison of measured affinity to the physiological concentration of that ligand is always a useful guide to assess the quality of any purified enzyme.

An example to illustrate this comes from our work with purine nucleoside phosphorylase, showing the effects of oxidation. This effect on the enzyme was produced by storage at 4°C for 3 weeks or by direct chemical oxidation, and caused a significant increase in K_m for inosine from the normal value of 23 μM, to an elevated value of 242 μM [20]. As shown in Table 1, the physiological concentrations of inosine are much more consistent with the lower K_m value. This enzyme preparation was pure, and still retained its maximal activity (at high substrate concentration); but the increased K_m was evidence that the enzyme was not completely stable during storage. For this enzyme we also observed that it is inhibited by the pyrimidine nucleotides CTP (K_i = 118 μM) and UTP (K_i = 164 μM), as well as by P-ribose-PP (K_i = 5.2 μM). While none of these compounds had been previously observed as inhibitors, a comparison of their K_i values to their actual cellular concentrations indicates that purine nucleoside phosphorylase would be partly regulated by these compounds *in vivo*.

When making such comparisons of measured affinity to ligand concentrations, it is useful to think of such ligands as being either *general* or *specific*. A general ligand is one that is used by many different enzymes, such as ATP and kinases, while the specific ligand is usually the acceptor substrate in transfer reactions, and is the ligand for which the enzyme is commonly named. For the general ligand, enzymes usually have a K_m far below the physiological concentration of that ligand. As an example, total ATP concentrations are generally ≥ 3 mM, but kinases usually have a K_m for ATP that is <0.5 mM. These affinity values are con-

Table 7. Cell volumes

Cell type	Volume (ml/10^9 cells)	References
human erythrocytes	0.1	64
human lymphoblasts	2.1	36
hamster fibroblasts	2.6	64, 66
mouse fibroblasts and lymphomas	1.3	64, 101, 102
pig kidney	3.6	64
rat liver and hepatoma	3.4	64, 82
	intracell. vol	
tissue	*per g tissue (ml)*	
brain	0.8	103
erythrocytes	0.7	103
liver	0.8	103
muscle	0.8	103
mouse fibroblasts 3T3 (per 10^9 cells)	5.0	104

sistent with the expectation that the concentration of free ATP probably does not exceed 1 mM in the cell (a value of 170 μM has been observed in hepatocytes [18]), and implies that kinases are still adequately, if not fully, saturated with ATP at its actual available concentration. K_m values for the specific substrate are more likely to be comparable to the measured concentration of that substrate. Using kinases as an example, enzyme activity is more likely to be modulated by the available concentration of the specific acceptor being phosphorylated.

Table 8. Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
Adenine				
human erythrocytes	0.4	0.3		24
pig follicular fluid	60			21
rabbit erythrocytes	0.5			23
rabbit reticulocyte	3.3			23
rat liver	0.4			26
rat plasma	2.0			25
rat serum	8.0			27
Adenosine				
human erythrocytes	0.9	0.6		24
human fat	0.1			28
human placenta	42	33.3		29
rabbit erythrocyte	0.6			23
rabbit reticulocyte	3.6			23
rat cerebro-spinal fluid	1.0			28
rat liver	0.01			26
rat plasma	2.4			25
rat serum	8.0			27
AMP				
human blood	6.0			75
human eosinophils	3.5		9	87
human erythrocytes	12		1.2	87
human erythrocytes	17	12		24
human erythrocytes	247	173		76
human lymphocytes	1.5		4	87
human lymphocytes	23		47.8	88
human lymphocytes	70			48
human lymphoblasts	208		250	85
human monocytes	1.9		5	87
human neutrophils	2.3		6	87
mouse Ehrlich ascites cells	208	166		24
mouse leukemia L1210	186			8
mouse neuroblastoma	230		480	77
rabbit blood	66			23
rabbit erythrocytes	40			23
rabbit reticulocytes	141			23
rat brain (2 mos)	40	32		89
rat brain	31	25		89
rat heart	188	150		42
rat heart	120	96		90
rat hepatoma 3924A	343	274		63
rat hepatoma 9618A	486	389		63
rat hepatoma 8999	561	449		63
rat liver	6.8		30.6	105
rat liver	19	15		78
rat liver (2 mos)	19		28.8	105
rat liver	423	339		63
rat liver	450	360		79

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
dAMP				
mouse leukemia P388/D_1	12		25	73
ADP				
human blood	48			75
human eosinophils	22		58	87
human erythrocyte	171		12	87
human erythrocyte	191	134		24
human erythrocyte	871	610		76
human lymphoblasts	230		460	85
human lymphocytes	16		33	87
human lymphocytes	212		441	88
human lymphocytes	360			48
human monocytes	32		67	87
human neutrophils	24		49	87
mouse Ehrlich ascites cells	1,101	881		24
mouse leukemia L1210	550		1,100	86
mouse leukemia L1210	1,050			8
mouse neuroblastoma	1,394		2,900	77
rabbit blood	328			23
rabbit erythrocytes	310			23
rabbit reticulocytes	395			23
rat brain (2 months)	228	182		89
rat brain	309	247		89
rat heart	875	700		42
rat heart	887	710		90
rat hepatoma 3924A	973	778		63
rat hepatoma 8999	1,073	858		63
rat hepatoma 9618A	1,215	972		63
rat liver	948	758		78
rat liver	982	786		63
rat liver	1,325	1,060		79
ATP				
human blood	433			75
human erythrocytes	1,519	1,063		76
human erythrocytes	1,629	1,140		24
human erythrocytes	1,871		131	87
human lymphocytes	390		812	87
human lymphocytes	463		948	88
human lymphocytes	1,900			48
human lymphocytes	2,303		4,790	85
mouse Ehrlich ascites cells	1,827		3,800	64
mouse Ehrlich ascites cells	2,950	2,360		81
mouse Ehrlich ascites cells	3,140	2,512		64
mouse leukemia L1210	2,740		5,700	86
mouse leukemia L1210	4,520			8
mouse leukemia P388/D_1	1,563		3,250	73
mouse lymphoma L5178Y	2,195		1,932	80
mouse neuroblastoma	9,426		18,100	77
rabbit blood	2,403			23
rabbit erythrocytes	1,395			23
rabbit reticulocytes	3,580			23
rat hepatoma 3924A	1,206	965		63
rat hepatoma 8999	1,763	1,410		63
rat hepatoma 9618A	2,256	1,805		63
rat brain (2 months)	3,175	2,540		89
rat brain	3,325	2,660		89
rat heart	5,138	4,110		42

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
rat liver	2,788	2,230		79
rat liver	3,044		10,960	82
rat liver	3,050	2,440		83
rat liver	3,088	2,470		63
rat liver	4,300	3,440		78
rat hepatoma 3924A	1,206	965		63
rat hepatoma 3924A	1,261		5,045	67
rat hepatoma 8999	1,763	1,410		63
rat hepatoma 9618A	2,256	1,805		63
rat Novikoff hepatoma	6,510		12,500	84
dATP				
human fibroblasts HeLa	3.6		7.4	65
human lymphocytes	1.3		2.6	68
human lymphocytes	2.3		4.8	7
baby hamster kidney cells	8.9		25	64
chinese hamster ovary cells	27			66
mouse fibroblasts 3T3	62		96	64
mouse fibroblasts L929	12		15	64
rat hepatoma 9618A	4.7	3.7		63
rat hepatoma 8999	5.9	4.7		63
rat hepatoma 3924A	22	17.7		63
rat hepatoma 3924A	34		135	67
rat liver	1.5		1	63
Cytidine				
human plasma	0.6			32
human plasma (female)	0.7			32
human plasma (children)	<2			34
dog plasma	1.0			31
guinea pig plasma	3.9			31
rabbit plasma	4.8			31
rat cerebro-spinal fluid	2.0			35
rat plasma	3.3			32
rat plasma	5.2			25
rat plasma	5.4			30
rat plasma	8.6			33
rat serum	10			27
deoxyCytidine				
human plasma	<0.5			31
human plasma	0.7			22
dog plasma	26			31
guinea pig plasma	1.4			31
rabbit plasma	2.3			31
rat cerebro-spinal fluid	1.0			35
rat plasma	1.4			35
rat plasma	23			25
rat plasma	41			31
Cytosine				
human plasma	1.4			31
human plasma	1.7			31
dog plasma	0.9			31
guinea pig plasma	0.4			31
rabbit plasma	2.2			31
rat plasma	1.1			30
rat plasma	10			25
rat serum	24			27

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
CMP				
human erythrocyte	0	0		76
human blood (leukemia patient)	96		200	106
human leukocytes	38		80	106
mouse leukemia L1210	36			8
mouse liver	14			69
mouse lymphoma S-49	8.4		8.4	69
rat hepatoma 9618A	36	29		63
rat hepatoma 8999	50	40		63
rat hepatoma 3924A	69	55		63
rat liver	41	33		79
rat liver	44	35		63
rat liver	4.8		21.7	105
rat liver (2 months)	25		37.9	105
dCMP				
human H-9 cells	1.9		4	74
mouse liver	0.2			69
mouse lymphoma S-49	0.4		0.34	69
CDP				
human eosinophils	0.5		1	87
human erythrocyte	0	ND		76
human erythrocyte	0		ND	87
human lymphocytes	0		ND	87
human monocytes	1.4		3	87
human neutrophils	0.5		1	87
mouse leukemia L1210	190			8
mouse liver	4.1			69
mouse lymphoma S-49	21		20.9	69
rat hepatoma 8999	53	42		63
rat hepatoma 9618A	54	43		63
rat hepatoma 3924A	63	50		63
rat liver	44	35		63
rat liver	70	56		63
dCDP				
human H-9 cells	0.1		0.2	74
mouse liver	0.1			69
mouse lymphoma S-49	1.7		1.7	69
CTP				
human eosinophils	23		47	87
human erythrocytes	0	ND		76
human erythrocytes	0		ND	87
human lymphocytes	10		21.5	87
human lymphocytes	380		790	85
human monocytes	28		58	87
human neutrophils	15		32	87
chick embryo fibroblast	25		90	64
mouse fibroblasts 3T3	419		1,500	64
mouse leukemia L1210	689			8
mouse liver	3.6			69
mouse lymphoma S-49	166		166	69
mouse neuroblastoma	447		1,600	77
rat hepatoma 9618A	94	75		63
rat hepatoma 8999	96	77		63
rat hepatoma 3924A	140		560	67
rat hepatoma 3924A	259	207		63

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
rat Novikoff hepatoma	253	500		92
rat Novikoff hepatoma	422	810		84
rat Novikoff hepatoma	427	820		64
rat brain (2 months)	220	176		89
rat brain	90	72		89
rat liver	50	40		79
rat liver	53		190	82
rat liver	71	57		63
rat liver	100	80		83
rat liver	143	114		47
dCTP				
human fibroblasts HeLa	20		31	65
human H-9 cells	0.3		0.5	74
human lymphocytes	0.7		1.4	68
human lymphocytes	2.0		4.2	7
baby hamster kidney	23		65	64
chinese hamster ovary fibroblasts	33		48	66
mouse liver	0.1			69
mouse lymphoma S-49	18		18.1	69
mouse lymphoma S-49	54		56	64
mouse lymphoma S-49	37		38	64
rat liver	7.4	5.9		63
rat hepatoma 9618A	9.1	7.3		63
rat Novikoff hepatoma	5.7		11	62
rat hepatoma 9618A	9.1	7.3		63
rat hepatoma 8999	23	18.6		63
rat hepatoma 3924A	66	52.5		63
Guanine				
human lymphoblasts	97			36
rat plasma	0.4			25
Guanosine				
human serum	0.9			37
rat plasma	0.3			25
rat serum	3.0			27
GMP				
human eosinophils	2.0		4.1	87
human erythrocytes	0		ND	87
human lymphocytes	1.0		2	87
human lymphocytes	7.3		14.9	88
human lymphocytes	30			48
human lymphocytes	34		70	85
human monocytes	2.4		5	87
human neutrophils	1.4		3	87
mouse Ehrlich ascites cells	148	118		24
mouse leukemia L1210	19			8
mouse neuroblastoma	140		140	77
rat hepatoma 3924A	65	52		63
rat hepatoma 9618A	71	57		63
rat hepatoma 8999	84	67		63
rat liver	20	16		79
rat liver	3.6		16.2	105
rat liver	41	33		63

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
dGMP				
mouse leukemia P388/D_1	9.1		19	73
GDP				
human eosinophils	1.7		3.5	87
human erythrocytes	14	10		24
human erythrocytes	16		1.1	87
human lymphocytes	5.8		12	87
human lymphocytes	29.7		60.9	88
human lymphocytes	70			48
human lymphocytes	72		150	85
human monocytes	14		30	87
human neutrophils	17		35	87
human platelets	2.3		4.8	87
mouse Ehrlich ascites cells	287	201		24
mouse leukemia L1210	115		240	86
mouse leukemia L1210	200			8
rabbit erythrocytes	63			23
rabbit reticulocytes	95			23
rat brain (2 months)	101	81		89
rat brain	156	125		89
rat heart	100	80		90
rat liver	121	97		63
rat liver	140	112		79
rat hepatoma 8999	148	118		63
rat hepatoma 3924A	171	137		63
mouse neuroblastoma	212		440	77
GTP				
human eosinophils	138		286	87
human erythrocytes	86	60		24
human erythrocytes	64		4.5	87
human leukemia HL-60	543		1,130	91
human lymphocytes	72		150	87
human lymphocytes	86		176.8	88
human lymphocytes	310			48
human lymphocytes	582		1,210	85
human monocytes	140		291	87
human neutrophils	185		384	87
chick embryo fibroblasts	47		170	64
mouse Ehrlich ascites	240		500	64
mouse Ehrlich ascites	799	639		24
mouse fibroblasts 3T3	528	1,900		64
mouse leukemia L1210	449			8
mouse leukemia L1210	481		1,000	86
mouse leukemia P388/D_1	108		225	73
mouse neuroblastoma	875	3,150		77
rabbit erythrocytes	216			23
rabbit reticulocytes	680			23
rat brain (2 months)	651	521		89
rat brain	551	441		89
rat heart	188	150		90
rat heart	238	190		42
rat hepatoma 9618A	313	250		63
rat hepatoma 8999	324	259		63
rat hepatoma 3924A	356		1,425	67
rat hepatoma 3924A	405	324		63
rat Novikoff hepatoma	729		1,400	64
rat liver	344		1,240	82

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
rat liver	388	310		83
rat liver	390	312		63
rat liver	443	354		47
rat liver	464	371		79
rat liver	1,028		3,700	64
dGTP				
human fibroblasts HeLa	6.4		10	65
human lymphocytes	0.4		0.9	68
human lymphocytes	2.9		6.1	7
baby hamster kidney fibroblasts	1.4		3.8	64
chinese hamster ovary fibroblasts	1.3		1.9	66
mouse fibroblasts 3T3	15		24	64
mouse fibroblasts L929	13		17	64
rat hepatoma 9618A	1.7	1.3		63
rat hepatoma 8999	2.7	2.2		63
rat hepatoma 3924A	5.4	4.3		63
rat hepatoma 3924A	8.6		34.5	67
rat liver	1.3	1		63
Hypoxanthine				
human placenta	284	227		29
human plasma	0.5			40
human plasma	1.0			39
human plasma	1.2			41
human serum	<10			38
porcine follicular fluid	1,410			21
rabbit erythrocyte	13			23
rabbit reticulocyte	68			23
rat cerebro-spinal fluid	4.5			35
rat heart	138	110		42
rat liver	0.2			26
rat plasma	0.1			25
rat plasma	5.1			35
Inosine				
human brain	750			44
human cerebro-spinal fluid (adult)	1.8			45
human cerebro-spinal fluid (adult)	4.0			43
human cerebro-spinal fluid (newborn)	0.6			45
human placenta	85	68		29
human plasma	0.5			40
human plasma	1.0			39
human plasma	1.2			41
human serum	5.6			37
rabbit erythrocytes	2.5			23
rabbit reticulocytes	41			23
rat cerebro-spinal fluid	1.2			35
rat liver	0.2			26
rat plasma	0.5			25
rat plasma	1.6			35
rat serum	20			27
IMP				
human eosinophils	11		22	87
human erythrocytes	100	70		24
human erythrocytes	14		1	87
human lymphocytes	1.0		2	87

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
human monocytes	24		49.1	88
human monocytes	2.9		6	87
human neutrophils	11		23	87
rabbit erythrocytes	50			23
rabbit reticulocytes	110			23
rat heart	114	91		90
rat hepatoma 3924A	89		355	67
rat liver	10	8		79
rat liver	39	31		63
Orotate				
human lymphoblasts	<10		<20	48
human serum	<0.045			46
mouse leukemia L1210	132			8
rat liver	0.5	0.4		47
rat plasma	0.2			49
Orotidine				
human erythrocytes	20			50
human erythrocytes (renal failure)	221			50
human plasma	5			50
mouse leukemia L1210	149			8
OMP				
mouse leukemia L1210	16			8
rat liver	0.1	0.07		47
Thymine				
rat plasma	0.1			25
rat serum	4.7			27
DeoxyThymidine				
human plasma (cancer patients)	0.8			22
fetal calf serum	1.4			51
fetal calf serum	13			53
horse serum	0.2			51
mouse serum	1.0			52
rat cerebro-spinal fluid	0.6			35
rat plasma	0.6			35
rat plasma	1.3			25
rat serum	13			27
dTMP				
human H-9 cells	1.4		2.8	74
mouse liver	0.5			69
mouse lymphoma S-49	0.5		0.52	69
dTDP				
human H-9 cells	2.4		4.9	74
mouse liver	0.2			69
mouse liver	0.6			69
mouse lymphoma S-49	3.7	3.4	69	
dTTP				
human HeLa cells	39		82	65
human H-9 cells	4.1		8.6	74
human lymphoblasts	19		40	70

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
human lymphocytes	0.7		1.4	7
human lymphocytes	5.8		12.1	68
baby hamster kidney fibroblasts	11		31	64
chinese hamster ovary fibroblasts	29		38.4	66
E. coli	100			71
mouse leukemia P388/D_1	89		185	73
mouse lymphoma S-49	22		19.9	69
mouse fibroblasts 3T3	49		77	64
mouse fibroblasts 3T6	58		90	64
mouse fibroblasts L929	51		80	64
rat liver	0.9	0.7		63
rat liver	1.6	1.3		63
rat hepatoma 9618A	1.9	1.5		63
rat hepatoma 8999	4.0	3.2		63
rat hepatoma 3924A	11	8.5		63
rat hepatoma 3924A	25		47	67
rat Novikoff hepatoma	22		42	62
Uracil				
human plasma	1.0			54
human plasma (male)	1.0			31
human plasma (female)	1.8			31
dog plasma	0.7			31
guinea pig plasma	0.5			31
pig follicular fluid	440			21
rabbit plasma	5.0			31
rat plasma	1.7			31
rat plasma	2.9			25
rat serum	24			27
Uridine				
human cerebro-spinal fluid (newborn)	3.5			45
human cerebro-spinal fluid (adult)	1.8			45
human cerebro-spinal fluid (adult)	3.9			43
human cerebro-spinal fluid (head injury)	0.4			43
human plasma	4.5			40
human plasma	4.8			41
human plasma	4.3			54
human plasma	3.1			58
human plasma	3.5			57
human plasma	4.5			31
human plasma (children)	2.5			34
human plasma (male)	4.9			31
human plasma (female)	21			22
human serum	3.0			60
human serum	3.2			37
human serum	4.5			40
human serum	5.1			61
human serum	5.4			60
human serum	15			55
calf serum	3.8			58
dog plasma	<3			31
fetal calf serum	5.1			58
guinea pig plasma	13			31
mouse cells HCT-8	9.0			56
mouse cells W256	12.1			56
mouse colon tumor	7.3			56
mouse fibroblasts L1210	9.2			56

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
mouse intestine	13			56
mouse kidney	31			56
mouse liver	27			56
mouse lymphoma L5178Y	7.9			56
mouse mast cell P388	8.4			56
mouse plasma	1.2			30
mouse plasma	3.2			56
mouse sarcoma 180	6.9			56
mouse serum	5.0			58
mouse serum	10			61
mouse spleen	38			56
rabbit cerebro-spinal fluid	7.6			35
rabbit plasma	8.5			35
rabbit plasma	11			31
rat plasma	0.9			32
rat plasma	1.2			30
rat plasma	2.4			25
rat plasma	3.6			33
rat plasma	3.9			58
rat serum	6.5			61
DeoxyUridine				
human plasma	0.6			22
rat cerebro-spinal fluid	1.1			35
rat Novikoff hepatoma	0.2		0.3	62
rat plasma	0.5			35
UMP				
human erythrocytes	0	0		76
mouse leukemia L1210	77			8
mouse liver	301			69
mouse lymphoma S-49	15		15.2	69
rat brain (2 months)	28	22		89
rat brain	18.9	15		89
rat liver	38	30		83
rat liver	5.4		19.5	105
rat liver	90	72		63
rat liver	259	207		47
rat liver	301			69
rat liver	370	296		79
rat hepatoma 9618A	170	136		63
rat hepatoma 3924A	196	157		63
rat hepatoma 8999	364	291		63
dUMP				
human H-9 cells	4.8		10	74
human lymphoblasts	0.5		1	70
mouse liver	0.2			69
mouse lymphoma S-49	<0.1		<0.1	69
rat Novikoff hepatoma	6.3		12	62
UDP				
human eosinophils	2.8		6	87
human erythrocytes	0		ND	87
human erythrocytes	0	ND		76
human lymphocytes	2.4		5	87
human monocytes	5.8		12	87
human neutrophils	2.9		6	87
mouse Ehrlich ascites cells	40	32		24

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
mouse leukemia L1210	331			8
mouse liver	50			37
mouse lymphoma S-49	108		108	37
mouse neuroblastoma	410		850	77
rat brain (2 months)	55	44		89
rat brain	24	19		89
rat liver	50			37
rat liver	75	60		83
rat liver	140	112		63
rat liver	161	129		63
rat liver	170	136		47
rat liver	263	210		79
rat hepatoma 9618A	131	105		63
rat hepatoma 8999	160	128		63
rat hepatoma 3924A	311	249		63
dUDP				
human H-9 cells	1.0		2	74
human lymphoblasts	0.02		0.05	70
mouse liver	<0.1		<0.1	69
mouse lymphoma S-49	<0.1		<0.1	37
UTP				
human eosinophils	65		135	87
human erythrocytes	0	ND		76
human erythrocytes	2.9		0.2	87
human lymphocytes	56		116	87
human lymphocytes	942		1,960	85
human monocytes	140		291	87
human neutrophils	61		127	87
human platelets	0.2		0.41	87
chick embryo fibroblasts	56		200	64
mouse Ehrlich ascites cells	124	99		24
mouse Ehrlich ascites cells	264		550	64
mouse fibroblasts 3T3	865		3,100	64
mouse leukemia L1210	1,460			8
mouse liver	29			37
mouse lymphoma S-49	609		560	37
mouse lymphoma L5178Y	519		470	64
mouse neuroblastoma	1,808		3,760	77
rat hepatoma	825	660		92
rat hepatoma 9618A	266	213		63
rat hepatoma 8999	285	228		63
rat hepatoma 3924A	318		1,270	67
rat hepatoma 3924A	321	257		63
rat brain (2 months)	973	778		89
rat brain	260	208		89
rat liver	295	236		47
rat liver	325	260		83
rat liver	338	270		79
rat liver	370	296		63
rat liver	379	303		63
rat liver	419		1,510	82
rat liver	551	441		47
rat Novikoff hepatoma	1,133		2,175	84
rat sarcoma 180	380		380	64
dUTP				
human lymphoblasts	<0.0003		<0.3 pmol	70

Table 8 (Contd.). Specific concentrations of purine and pyrimidines

Compound (source)	Concentration (μM)	nmoles/ g wet wt.	nmoles/ 10^9 cells	Reference
E. Coli	0.5			107
mouse fibroblasts 3T6	0.2		0.4	72
mouse liver	0.1			69
mouse lymphoma S-49	<0.1		<0.1	69
Xanthine				
human brain	125			44
human cerebro-spinal fluid (adult)	1.8			45
human cerebro-spinal fluid (adult)	3.3			43
human cerebro-spinal fluid (newborn)	5.0			45
human erythrocytes	3.6	2.5		24
human plasma	0.4			40
human plasma	4.9			39
human serum	2.6			37
rat heart	50	40		42
rat liver	0.5			26
XMP				
human lymphocytes	7.3		14.9	88
rat liver	4.0	3		79
rat liver	4.0	3		63

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