Fun with Flags and Chemistry

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1 Fun with Flags and Chemistry

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ABSTRACT: The purpose of this study is to present a learning activity that combines the simultaneous practice of geography and chemistry. It is a game activity based on the identification of national flags and colored molecules (from the famous CPK model), with an extension to the creation of imaginary flags from real, useful molecules for middle school, high school, and university classrooms. The goal of using a game is to motivate/involve learners, to encourage them to work and develop adaptability and responsiveness by practicing chemistry and geography components. The feedback received from students who participated in this exercise during the 2019–2020 academic year has been evaluated and shows an increase of motivation and critical thinking. The objective is to make students more aware of geopolitics, to engage discussion on their awareness of the world, and to prepare them to play an active role in it.

KEYWORDS: Humor/Puzzles/Games, Pedagogy, Interdisciplinary/Multidisciplinary, Domain, General Public, Audience, History/Philosophy, Domain, Molecular Properties/Structure, Topics

19 ■ INTRODUCTION

If we are to face the great challenges of the 21st century^{1,2} (clean energy, sustainable cities, climate action, good health, etc.), a new approach is required for education.^{3–5} The next generation will have to solve important national or global problems to create the industries and jobs of the future; expand the frontiers of human knowledge about ourselves and the world around us; and tackle important problems related to energy, health, education, the environment, national security, and global development. Interaction between social sciences and natural sciences is a necessary condition for success in this endeavor and an important part of the modernization of the educational process in regard to these challenges. For example, the new technologies and devices that enriched our lives in the 21st century require rare earth metals.⁶ Future engineering should be sensitive to the planet's natural resources,⁷ their location, the reserves available, and possible substitute products. Therefore, teaching the next generation will require a multidisciplinary approach:⁸ a combination of natural science, technology, innovation, and social science to help them face the challenge of managing the world's resources. Some educators have already developed innovative, multidisciplinary approaches⁹ to teaching geography, chemistry, and ecology together,¹⁰ or combining geography, math, and science to teach climate change and sea level rise.¹¹ The results of this research suggest that most students view such developments positively and recognize that they bring many advantages, such as critical thinking and a broadening of their knowledge horizons.¹² In the perspective of developing a new educative activity in this direction, humanities

and chemistry could be associated, and this paper presents an original, engaging activity to help students to connect chemistry and geography. It was developed on a game based on recognizing flags with simple chemical molecules and is named "Fun with Flags" in reference to episode 14 of the fifth season of *The Big Bang Theory*,¹³ an American television sitcom created by Chuck Lorre and Bill Prady in 2007, where two of the main characters present a YouTube podcast on the topic of vexillology¹⁴ (term created by Whitney Smith in 1958 from the Latin word vexillum/"flag" and the Greek suffix -logia /"study") named "Sheldon Cooper Presents: Fun With Flags". In this fictional video podcast, several "fun facts" about flags, such as the shape, the presence of animals, or the origins of the flags, are presented in an entertaining way. Using pop-culture references^{15–18} is an interesting approach to improve students' motivation,¹⁷ and several educators have developed educational games^{19–22} to involve students in interactive, entertaining activities.²³ Games are an excellent method of active learning in a recreational environment,²⁴ and many methods have been tested in the past decade:²⁵ a word game,²⁶ quiz games,^{27–35} card games,^{36–38} dice games,^{39,40} board games,^{41–46} computer games,^{47–49} memory/concentration games,^{50–52} and even

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Figure 1. (a) CPK model. (b) Mass fraction in the universe in % plotted against the percentage of flags containing the color. (c) Representation of the atom fraction in parts per million in the universe plotted against the percentage of flags containing the color (refs 73 and 74). Hydrogen mass fraction in the universe is 70.57%, and white is present in 72.92% of flags and in 19.12% of the surface.

70 escape games.^{53–58,58–61} All of these educators have succeeded
71 in creating a recreative environment improving the student's
72 engagement and motivation for science.

73 The link between flags and chemistry has already been
74 attempted by educators, only on the basis of the chemistry
75 necessary to produce the colored dyes.⁶²

76 Some authors have tried to connect objects with molecules in
77 order to create a recreative environment, such as structural
78 chemical formulas with human forms (called NanoPutians),⁶³
79 monsters (NanGobelin),⁶⁴ or racing car shapes.^{65,66} The goal of
80 these studies was to educate children in the sciences in an
81 effective and enjoyable manner. They have made several videos
82 featuring the NanoPutians as anthropomorphic animated
83 characters. In order to relate vexillology with chemistry, and in
84 the following of these *chemistrymorphisms*, we propose to create
85 a game on the manipulation of colored atoms looking like the
86 real flags. In 1952, Corey and Pauling published a description of
87 space-filling models of proteins and other biomolecules that they
88 had been building at Caltech.⁶⁷ Their models represented atoms
89 by faceted hardwood balls, painted in different colors to indicate
90 the component chemical elements. Their color scheme included
91 the following: white for hydrogen, black for carbon, blue for
92 nitrogen, and red for oxygen (Figure 1a). In 1965, Koltun
93 patented⁶⁸ an improved version of the Corey and Pauling
94 modeling technique. In his patent, he added several colors:
95 yellow for sulfur, purple for phosphorus, green for the halogens
96 (F, Cl, Br, I), and silver for metals. This model is known as the
97 CPK model (for Corey, Pauling, and Koltun). Several of the
98 CPK colors refer mnemonically to colors of the pure elements or
99 notable compounds (hydrogen is a colorless gas; carbon, as
100 charcoal, graphite, or coke, is black; sulfur powder is yellow;
101 chlorine is a greenish gas; etc.). This molecular model is typically
102 used by students in introductory organic chemistry courses to
103 represent bonds and atoms with small plastic polygons or
104 spheres,^{69,70} and the models are helpful when students are
105 learning about molecular geometry and stereochemistry. This
106 paper describes an activity to link national flags to simple
107 chemical molecules of the same color (according to the CPK
108 code) in order to make students manipulate geography and
109 chemical concepts simultaneously. This activity can be done
110 remotely for distance learning^{7,54,60,71} from middle school to

university level (with an adaptation of the discussion, see the
Discussion section).

RELATIONSHIP BETWEEN FLAGS AND THE CPK MODEL

There are numerous flags in the world, representing the different
geographical, ethnic, religious, and national groups of human-
kind. A flag is more than an image or a scrap of fabric, it can be a
part of an individual's identity and a visual representation of a
collective. According to the United Nations, there is a total of
193 sovereign states in the world (and 2 observers states), and
each one has a recognizable national flag.⁷² The most frequent
type is the three-colored flag (40% of flags), followed by two-
and four-colored flags (20% each).⁷³ Red is the most widely used
color by percentage surface area and by number of flags (Figure
1b). The second color in the ranking is not the same by area and
by frequency (blue or white), as shown in Figure 1b,c. It is
noteworthy that the colors originally chosen for the CPK model
are very similar to the colors present in the flags of the world's
nations.

It is also worth noting that there is a similarity in value for
some colors/atoms between the presence in flags and presence
in the universe. For example, the hydrogen atom (white in the
CPK model) is present at 70.57% in the universe and appears in
72.92% of the flags while the phosphorus atom (purple) is
present at less than 0.1% in the universe or in national flags
(purple is used only in the flags of Spain, Nicaragua, and Sri
Lanka and in a small proportion). This demonstrates a good
probability of identifying flags and molecules with the same
colors. The only exception is for the color orange, which is not
included in the original CPK model but is present in 4.6% of
flags (1.2% of surface area), excluding flags of Ireland, India,
Côte d'Ivoire, and a few other countries from our analysis. In
vexillology there are many geometrical flag designs: *cantons* (a
flag divided in four equal quarters), *pales* (a flag divided into 2 or
3 vertical bands), *fesses* (a flag divided into three horizontal
bands), *saltire* (a flag with a diagonal cross), and *Scandinavian
cross* (a flag with a cross, the vertical arm of which is positioned
more toward the hoist). Two thirds of all national flags include
the use of symbols (sometimes even more than one) such as a
star (30%), emblem (14%), cross (9%), sun (8%), or crescent
(7%). Most flags are based on a simple formula of colors, 151

152 symbols, and layouts, and this results in as many differences as
 153 surprising similarities. 53% of all national flags are designed with
 154 a simple band layout, and the three-stripe design is by far the
 155 most popular, with over 80 national flags. The most widely used
 156 combinations are red–blue–white (30 flags), red and white (16
 157 flags), green–white–red (12 flags), red–yellow–white (11
 158 flags), and white–blue (10 flags).

159 ■ METHODOLOGY

160 Students from two separate courses used the game activity as a
 161 homework project after attending a series of lectures (10 h)
 162 covering an introduction to chemistry. The 87 students who
 163 participated came from either a Chemical Engineering course
 164 (class 1, 56 students, in 2020) or an Introduction to Chemistry
 165 master course (class 2, 31 students, in 2020). At the end of the
 166 activity, the teacher invited all students to evaluate the activities
 167 by completing an online form in French containing 10 questions
 168 with responses based on the Likert⁷⁵ scale. Participants were
 169 approached twice by email, and the response rate was 80%. The
 170 data from the online surveys were entered into a Microsoft Excel
 171 spreadsheet and were collated. All responses were analyzed, and
 172 the results are presented in the next section.

173 ■ ACTIVITY

174 The core of the activity is based on quizzes concerning the
 175 identification of the country from a simple molecule
 176 representing the associated flag. The objectives of the activity
 177 are to make student practice the CPK model (memorizing color
 178 and atoms), to manipulate the molecular geometry (VSEPR
 179 theory), and also to initiate discussions on resource localization
 180 and geopolitics and culture and history. We will first restrict the
 181 activity to band type flags with one to four colors in order to
 182 propose perfect matching or quasiperfect matching between the
 183 flags and chemical molecules of 1–4 atoms, and we will neglect
 184 all the symbols (emblem, cross, coat of arms, etc.) or differences
 185 in shape ratio to simplify the problem. After what was, to the best
 186 of our knowledge, a complete analysis of all national flags, we
 187 found only 10 “perfect matches” between existing flags and
 188 existing chemical compounds, with the right color, the right
 189 order of the colors, and the correct number of colors (4 for
 190 bicolor flags, and 6 for tricolor flags) and 20 quasiperfect
 191 matches (where the colors were correct but not the number of
 192 colors or the order of the colors). Figure 2 depicts the 10 “perfect
 193 matches”: from left to right, the flags are Gabon (Figure 2a, it
 194 could also work for Rwanda in the reverse order), Estonia
 195 (Figure 2b), Monaco/Indonesia/Singapore (Figure 2c; it could
 196 work for Poland in the reverse order), Algeria (Figure 2d; it
 197 could also work for Pakistan in the reverse order and Wales with
 198 a rotation), Russia/Slovakia/Slovenia (Figure 2e), Spain
 199 (Figure 2f), Romania/Moldavia/Chad (Figure 2g), Belize
 200 (Figure 2h), Nigeria (Figure 2i), and Portugal (Figure 2j; it
 201 could also work for Burkina Faso with a 90° rotation). The
 202 molecules used to recreate the flags are given in the legend of the
 203 figure.

204 This first series of flags is considered as easy due to the perfect
 205 match of color/order/number of colors between a flag and its
 206 CPK representation. It allows a total of 16 countries to be
 207 manipulated (depending on the orientation of the molecule).
 208 This series provides a good introduction to the activity and
 209 permits a focus on the similarity of certain flags in the world.

210 The second series concerns quasiperfect matching, where the
 211 number of atoms and their colors are identical to the number of

Figure 2. Molecular flags built with the CPK model for (a) Gabon/Rwanda—CINS thiazyl chloride; (b) Estonia—HCN hydrogen cyanide; (c) Monaco/Indonesia/Singapore—OH[−] hydroxide; (d) Algeria—HCL hydrochloric acid; (e) Russia/Slovakia/Slovenia—HNO nitroxyl; (f) Spain—OSO sulfur dioxide; (g) Romania/Chad/Moldavia/Andorra—OSN[−] sulfinylazanide; (h) Belize—NO₂[−] nitrite; (i) Nigeria—HF₂[−] bifluoride; (j) Portugal—ClO[−] hypochlorite.

bands and the colors of an existing flag, but not the order. The
 difficulty is thus greater than in the first series. Figure 3 depicts 5

Figure 3. Molecular flags built with the CPK model for: (a) Austria/Peru—OHO hydroperoxyl; (b) Belgium/Germany—OCS carbonyl sulfide; (c) Bulgaria/Italy/Hungary/Iran/Mexico/Tajikistan—HClO hypochlorous acid; (d) Mauritius—ClNOS sulfinylamino chloride; (e) Barbados—N₂S dinitrogen-*N*-sulfide.

“quasiperfect matches”. From left to right, the flags are Austria/Peru (Figure 3a), Belgium/Germany (Figure 3b), Bulgaria/Italy/Hungary/Iran/Mexico/Tajikistan (Figure 3c), Mauritius (Figure 3d), and Barbados (Figure 3e). The molecules used to recreate the flags are given in the legend of the figure.

Note that “perfect match” flags could also be used for “quasiperfect” matching: Figure 2e could be used in that context for the flags of France/Netherlands/Luxemburg/Croatia/Czech Republic, and Figure 2e could be used for the flags of Colombia/Ecuador/Armenia/Venezuela. This second series of flags allows a total of 20 supplementary countries to be manipulated. The difficulty is higher due to the fact that colors are not in the right order, but as there is often more than one solution for each molecule, the possibility of success is good. The third series proposed concerns the “imperfect matches” where the color of the flags and the molecules are the same, but the order or the number of colors are not correct, making this category the hardest one. Figure 4 depicts the 17 “imperfect matches”. Starting with the band flag, at the top, from left to right: Somalia (Figure 4a), Argentina/Salvador/Guatemala/Honduras/Israel (Figure 4b), Vatican (Figure 4c), Bolivia/Lithuania/Cameroon/Republic of the Congo/Guinea/Mali/Senegal/Ethiopia/Myanmar (Figure 4d), Sierra Leone/Uzbeki-

Figure 4. Molecular flags built with the CPK model for (a) Somalia— N_2 nitrogen; (b) Argentina/Salvador/Guatemala/Honduras/Israel— NH_3 ammonia; (c) Vatican— H_2S hydrogen sulfide; (d) Bolivia/Lithuania/Cameroon/Republic of the Congo/Guinea/Mali/Senegal/Ethiopia/Myanmar— Cl_2OS thionyl chloride; (e) Sierra Leone/Uzbekistan/Lesotho— NH_2Cl chloramine; (f) Yemen/Egypt/Syria/Iraq— CH_2O formaldehyde; (g) Azerbaijan— ClNO nitrosyl chloride; (h) Malawi/Afghanistan/Libya— CCl_2O phosgene; (i) Brazil— H_2ClNS amino thiophochlorite; (j) Ukraine/Congo/European Union/Kazakhstan/Sweden— N_2S dinitrogen-*N*-sulfide; (k) Oman— HClO hypochlorous acid; (l) Turkey/Tonga/Switzerland/Tunisia/Japan/Denmark/Canada/Bahrain— OH^- hydroxide; (m) China/Kyrgyzstan/North Macedonia/Vietnam— SO sulfur monoxide; (n) Bahamas— CN_2S thiocyanamide; (o) South Korea— CHNO cyanic acid; (p) Jamaica— CCl_3S thiophosgene; (q) South Africa/Olympic Flag— CH_2ClNOS *N*-sulfanylcabamoyl chloride.

phosphorus (P_4) a tetratomic molecule. Allotropes are different chemical forms of the same element (not containing any other element) that are homonuclear: sulfur forms several allotropes containing different numbers of sulfur atom (S_2 , S_3 , S_6 , S_8) forms. The element carbon is known to have several homonuclear molecules, including diamond and graphite. With these particular molecules, it is possible to establish single-color flags. Although no monocolour flags exist at the present time, there have been several in the past, as presented with the last series of flags in Figure 5.

Figure 5. Molecular flags built with the CPK model for: (a) Kingdom of France (1814–1830)— H_2 hydrogen; (b) Maldives (1796–1903)— O_2 oxygen; (c) Libya (1944–1971)— Cl_2 chlorine; (d) Russian Empire (1858–1883)— CH_2S thioformaldehyde; (e) Zanzibar (January–April 1964)— CClN cyanogen chloride; (f) Belarus (1991–1995)— H_2O water.

Figure 5 depicts the 5 “lost flags”, starting with the monocolour flags: from left to right, the flag of the former Kingdom of France (1814–1830) in Figure 5a (it could also work for the flag of peace or surrender), the former flag of the Maldives (1796–1903) in Figure 5b (this flag could also be used as an imperfect match for Morocco), the former flag of Libya (1944–1971) in Figure 5c, the band flag of the former Russian Empire (1858–1883) in Figure 5d, the former flag of Zanzibar (January–April 1964) in Figure 5e, and the former flag of Belarus (1991–1995), the last two of which are also perfect matches. This last series enables the student to manipulate specific homonuclear molecules and may also lead on to a discussion on the effect of political events and regime changes (royalty to democracy) that could lead to a change of the national flag. This last series also provides the opportunity to manipulate well-known molecules such as water (H_2O), which is one of the most famous molecules in the world. In order to encompass as many of the known molecules as possible, a last series is proposed. In this series, it is not the molecule that is represented but a fictional flag created on the basis of an existing well-known molecule. The 8 imaginary flags that can be found are depicted in Figure 6 and complete the list of famous molecules already used in the previous series (HCl , HCN , HClO , etc.).

These molecules can lead to a specific discussion on the complex shapes of flags and specific elements of vexillology (stripes, triangle, circle) and introduce the rare color purple. Discussion of the production of each molecule and the production locations in real countries is also possible. CPK colors are concentrated in the nonmetal part of the periodic table. To achieve brightly colored edifices, one should then imagine combinations with this restricted group of elements. This can lead to an interesting exploration of chemical literature: are such combinations stable? When have they been prepared? What for? What are their properties?

stan/Lesotho (Figure 4e), Yemen/Egypt/Syria/Iraq (Figure 4f), Azerbaijan (Figure 4g), and Malawi/Afghanistan/Libya (Figure 4h, which also works for the Pan-African flag). This series adds more than 27 countries, to give a total of 64 (triband flags that can be linked to a simple chemical molecule with several levels of difficulty).

In order to complete the analysis with nonband flags, including all the elements present in the flag this time, some other shapes are presented in Figure 4: at the bottom, from left to right, Brazil (Figure 4i), Ukraine/Congo/Kazakhstan/Sweden (Figure 4j, which also works for the European Union flag), Oman (Figure 4k), Turkey/Tonga/Switzerland/Tunisia/Japan/Denmark/Canada/Bahrain (Figure 4l), China/Kyrgyzstan/North Macedonia/Vietnam (Figure 4m), Bahamas (Figure 4n), South Korea (Figure 4o), Jamaica (Figure 4p), and South Africa (Figure 4q, which also works for the Olympic flag). This last series, which adds 23 extra countries, is more complicated to solve due to the complexity of certain flags such as those of Brazil or South Africa. A full table is proposed in the Supporting Information in order to list all the combinations of color possible with simple molecules for the 186 states of the United Nations. Another series of flags is also proposed. It is the most difficult one, based on flags that no longer exist. For this section, special attention has been paid to unicolor flags, which is open to discussion for specific molecules. This category implies matching the flag with a homonuclear molecule (molecule composed of only one type of element). The most familiar homonuclear molecules are diatomic (they consist of two atoms): hydrogen (H_2), oxygen (O_2), nitrogen (N_2), and all the halogens (an easy-to-remember mnemonic for the diatomic elements is “Have No Fear Of Ice Cold Beer” for hydrogen, nitrogen, fluorine, oxygen, iodine, chlorine and bromine). Ozone (O_3) is a triatomic homonuclear molecule and

Figure 6. Imaginary flags built with the CPK model from real molecules: (a) CH₃OH—methanol; (b) H₂PO₄—phosphoric acid; (c) CO₂—carbon dioxide; (d) HNO₃—nitric acid; (e) H₂SO₄—sulfuric acid; (f) CH₄—methane (g); C₇H₁₄—heptane.

Figure 7. Student responses relating to the use of "Fun with Flags and Chemistry". Total number of respondents = 87 (academic year 2019/2020).

agreed that this activity helped them to develop a multi-disciplinary outlook.

It is worth noting that a majority thought that this activity helped them to connect with other students (64.4%) and also with educators (62.1%). Finally, a large majority (93.1%) think that "Fun with Flags and Chemistry" is an excellent educational tool that can be used to practice chemistry and geography simultaneously. Using "Fun with Flags and Chemistry" is thus beneficial for the classroom because it creates engaging links between chemical concepts and geography, and between educators' and students' interests. The objective is to connect the student's knowledge in the two disciplines and to initiate discussions/debate on geopolitical aspects of both. Geography education research has worked hard to remove itself from the common misconception of geography education relating to memorizing (countries, capitals, and state/national flags). Here, the flag identification is not the end of the activity, it is a pretext to practice and manipulate CPK code and to discuss on geopolitics in a recreative environment; it is then an original approach for more discussion on advanced and modern topics.

Work can then be extended after the activity to think more deeply about where resources are located, independence of resources, global politics concerning resources, and the future societal challenge linked with the abundance of chemical compounds.

Educators need to be careful to open the boundaries of this activity so as to unleash the students' curiosity to think about facing these future problems. It is also important to leave the students free to search for information on chemistry, geography, or even history during projects/activities using all types of media, recent or not. Finally, combining geography and chemistry promotes critical thinking and develops skills in humanities, which will be important throughout the students' lives.

DISCUSSION

From all of these series of flags, simple quizzes could be organized with the students, where the objective is to find what molecule and what country (or countries) is (are) represented by each molecular flag. Some variations could be done to adapt the level of the activity from middle school to university such as letting (or not) the students have access to a database of flags in order to find the most difficult ones and even to an encyclopedia to identify flags from earlier times (see the [Supporting Information](#)). Teachers can let each student draw a molecule at random and let them find the corresponding flag, and the different characteristics of the country, and of the molecule. After the game, questions can be raised, based on the identification of capitals, continents, and the molar weight or the applications of the chemical compounds. It is also an opportunity to address the question of resources and its localization and about the gross domestic product (GDP) of each country. Moreover, combined questions can be elaborated such as "In which continent is Thiophosgene?" (Thiophosgene is Jamaica; answer is "america"), "What is the most Belgian molecule?" (answer is "carbonyl sulfide"), "Propose an existing molecule with the most common color combination (and name the country)" (there are 30 countries with the red-blue-white combination; see the list in the [Supporting Information](#) section), "What is the most populated molecule?" (sulfur monoxide corresponding to the Chinese flag) or "What is the molecule with the higher GDP?". According to the level targeted, and as a variation for the postgame discussion, a list of some of the countries/capitals/molecules can be proposed in front of molecular flags to create a matching game. Whatever the results of the game, the objective remains to practice basic knowledge of world flags and manipulation of the CPK model representation.

Students from two separate courses used the game activity and were surveyed after the activity with responses based on the Likert⁷⁵ scale (Figure 7). The response rate was 95%. In general, all statements showed high levels of agreement ("agree" and "strongly agree"), ranging from 62.1% to 93.1% of those surveyed.

A majority of students (89.7%) enjoyed the use of "Fun with

CONCLUSION

The objective of this paper is to present an original way to practice chemistry and geography simultaneously. The activity is based on the similarities of color observed in world national flags and in simple molecular models. With some simplifying hypotheses (band flags, approximation of colors, and neglect of coats of arms and symbols), and after a precise analysis of almost 200 national flags, several series of molecular flags have been proposed with several levels of difficulty, from perfect matching of colors, their number, and their order, to imperfect matching considering color matches only. These series were used as a base for a quiz game where the objective was to identify the country corresponding to the molecular flag. The feedback received from students that participated in this exercise has been evaluated and indicates an increase in motivation through such activities and their acceptance as a good multidisciplinary tool. The game was seen as a good exercise for practicing chemistry and geography, breaking down frontiers between disciplines, engaging students, and raising their awareness of the world's challenges. Such a combination of disciplines made it possible to start discussions about locations of resources and geopolitical or societal challenges of the future. The activity helped students to connect together, and to develop their own curiosity and creativity. It could be adapted to regional flags or those of province/state. To conclude, "Fun with Flags and Chemistry", the first ever attempt of chemo-vexillology, offers a wide range of possibilities for involving students in the classroom, from games to critical thinking, and from basic chemistry to human sciences.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00514>.

List of combination for the representation of the 195 UN nations flags (PDF, DOCX)

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Notes

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