International Journal of Advanced Research in Physical Science (IJARPS)
Volume 9, Issue 7, 2022, PP 1-6
ISSN No. (Online) 2349-7882
www.arcjournals.org

Coalescence of Water Droplets in Light of Alignment Energy

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Abstract: *Coalescence of water droplets with the easiest coordination and in the fewest steps is presented in light of alignment energy.*

Keywords: *Water droplets, alignment energy*

1. Introduction

Let us see how water droplets can coalesce with the easiest coordination and in the fewest steps in light of alignment energy [1].

2. Alignment Energy

Conceptual alignment energy [1] - enabling the alignment of the electron with its cluster nature - is given by the next formula:

$$E_{alignment} = \left(\frac{R_{unaligned}}{R_{aligned}} - 1\right) m_{electron} c^2. \tag{1}$$

Where $R_{unaligned}$ is the unaligned ratio of mass of the cluster to mass of the electron modified by the factor $\left(2 - \frac{1}{\sqrt{1+\pi^2}}\right)$ to obey double surface geometry [1] as follows:

$$R_{unaligned} = \frac{m_{cluster}}{m_{electron}} \left(2 - \frac{1}{\sqrt{1+\pi^2}}\right). \tag{2}$$

And round down value of $R_{unaligned}$ – justified in particular for large numbers in the case of huge clusters - is a good approximation of $R_{aligned}$:

$$R_{aligned} \approx ROUNDDOWN(R_{unaligned}). \tag{3}$$

Therefore, the following formula is useful for calculating the alignment energy of water droplets, too:

$$E_{alignment} \approx \left(\frac{R_{unaligned}}{ROUNDDOWN(R_{unaligned})} - 1\right) m_{electron} c^2. \tag{4}$$

With the help of key data:

$m_e = 0{,}000\ 548\ 579\ 909\ 065\ Da$

$m_{H2O} = 18{,}010\ 564\ 683\ 053\ Da$

$m_{electron} c^2 = 510\ 998{,}950\ 0\ \text{eV} = \text{h} . 1{,}235\ 589\ 964 \times 10^{20}\ \text{Hz}$

$Da = 1{,}660\ 539\ 066\ 6\ 10^{-24}\text{g}$

$h = Planck\ constant$

Of course, in order to recognize tiny differences between alignment energies, an exact equation has to be used [1]:

$$E_{alignment} = \left(\frac{R_{unaligned}}{s(n)} - 1\right) m_{electron} c^2. \tag{5a}$$

$$s(n) = n\left(2 - \frac{1}{\sqrt{1+\frac{\pi^2}{n^2}}}\right), n = ROUNDDOWN(R_{unaligned}). \tag{5b}$$

If the calculator fails at calculations with large numbers, a friendlier approximation formula for this occasion (See appendix 1) comes in handy:

$$s(n) \approx n\left(1+\frac{1}{2}\,\frac{\pi^2}{n^2}\right). \qquad (5c)$$

3. Discrete Mass

The mass of a droplet can take only discrete values because it can only consist of a natural number of molecules:

$$m_{drop} = n\ x\ m_{molecule},\quad n \in \mathbb{N}. \qquad (6)$$

4. Coalescence Related to Alignment Energy

Coalesced droplets in principle need lower energy for the alignment their essential Part with the Whole [1]. Breakup droplets need lower alignment energy only exceptionally what in general supports the coalescence of droplets and only in rare cases the breakup. Prudent forming of a huge droplet is realised by gradually merging two equal water droplets into one entity because coalescing of only two droplets requires the easiest coordination and for coalescing equal droplets the least steps are needed.

5. Prudent Coalescence of Water Droplets

We can start with the water droplet made of 1313 water molecules possessing practically the same alignment energy as the cluster made of 13 water molecules. [2] This energy equals the smallest alignment energy amongst energies of first 106 water clusters, expressed in frequency as follows:

$$\frac{E_{(H2O)_{13}}}{h} = 1{,}687\ THz\ \approx 1{,}688\ THz = \frac{E_{(H2O)_{1313}}}{h}. \qquad (7)$$

By coalescing gradually two equal water droplets in one entity a huge water droplet - even of a mass of the heaviest raindrop [3] - can be formed from the droplet $(H_2O)_{1313}$ in *n* steps:

$$m_{water\ droplet} = N_{H2O}\ x\ m_{H2O} = 2^n\ x\ 1313\ m_{H2O}. \qquad (8)$$

The findings are presented in Table1:

Table1. *Coalescence of two water droplets in one entity starting with the droplet consisted of 1313 water molecules what yields in n steps the droplet consisted of 2^n x 1313 water molecules*

$2^n\ x\ 1313$ ($n\epsilon\mathbb{N}$)	$R_{unaligned}$	$\frac{E_{alignment}}{h}(Hz)$	$m_{droplet}(g)$	$r_{droplet\ sphere}$	Tendency
$2^0\ x\ 1313$	73139756,9993	$1{,}688 \,.\, 10^{12}$	$3{,}927 \,.\, 10^{-20}$	r = 2,1 nm	↓
$2^1\ x\ 1313$	146279513,9986	$8{,}435 \,.\, 10^{11}$	$7{,}854 \,.\, 10^{-20}$	r = 2,7 nm	↓
$2^2\ x\ 1313$	292559027,9972	$4{,}212 \,.\, 10^{11}$	$1{,}571 \,.\, 10^{-19}$	r = 3,3 nm	↓
$2^3\ x\ 1313$	585118055,9945	$2{,}100 \,,\, 10^{11}$	$3{,}141 \,.\, 10^{-19}$	r = 4,2 nm	↓
$2^4\ x\ 1313$	1170236111,9890	$1{,}044 \,.\, 10^{11}$	$6{,}283 \,.\, 10^{-19}$	r = 5,3 nm	↓
$2^5\ x\ 1313$	2340472223,9780	$5{,}163 \,.\, 10^{10}$	$1{,}257 \,.\, 10^{-18}$	r = 6,7 nm	↓
$2^6\ x\ 1313$	4680944447,9559	$2{,}523 \,.\, 10^{10}$	$2{,}513 \,.\, 10^{-18}$	r = 8,4 nm	↓
$2^7\ x\ 1313$	9361888895,9118	$1{,}203 \,.\, 10^{10}$	$5{,}026 \,.\, 10^{-18}$	r = 11 nm	↓
$2^8\ x\ 1313$	18723777791,8236	$5{,}435 \,.\, 10^{9}$	$1{,}005 \,.\, 10^{-17}$	r = 13 nm	↓
$2^9\ x\ 1313$	37447555583,6473	$2{,}136 \,.\, 10^{9}$	$2{,}011 \,.\, 10^{-17}$	r = 17 nm	↓

$2^{10}\ x\ 1313$	74895111167,2946	$4{,}859 \cdot 10^{8}$	$4{,}021 \cdot 10^{-17}$	r = 21 nm	↔
$2^{11}\ x\ 1313$	149790222334,5891	$4{,}859 \cdot 10^{8}$	$8{,}042 \cdot 10^{-17}$	r = 27 nm	↕
$2^{12}\ x\ 1313$	299580444669,1782	$7{,}350 \cdot 10^{7}$	$1{,}608 \cdot 10^{-16}$	r = 34 nm	↔
$2^{13}\ x\ 1313$	599160889338,3564	$7{,}350 \cdot 10^{7}$	$3{,}217 \cdot 10^{-16}$	r = 43 nm	↑
$2^{14}\ x\ 1313$	1198321778676,7128	$7{,}350 \cdot 10^{7}$	$6{,}434 \cdot 10^{-16}$	r = 54 nm	↑
$2^{15}\ x\ 1313$	2396643557353,4256	$2{,}194 \cdot 10^{7}$	$1{,}287 \cdot 10^{-15}$	r = 68 nm	↔
$2^{16}\ x\ 1313$	4793287114706,8513	$2{,}194 \cdot 10^{7}$	$2{,}573 \cdot 10^{-15}$	r = 85 nm	↑
$2^{17}\ x\ 1313$	9586574229413,7026	$9{,}055 \cdot 10^{6}$	$5{,}147 \cdot 10^{-15}$	r = 0,11 µm	↓
$2^{18}\ x\ 1313$	19173148458827,4051	$2{,}611 \cdot 10^{6}$	$1{,}029 \cdot 10^{-14}$	r = 0,13 µm	↔
$2^{19}\ x\ 1313$	38346296917654,8103	$2{,}611 \cdot 10^{6}$	$2{,}059 \cdot 10^{-14}$	r = 0,17 µm	↓
$2^{20}\ x\ 1313$	76692593835309,6205	$9{,}997 \cdot 10^{5}$	$4{,}118 \cdot 10^{-14}$	r = 0,21 µm	↓
$2^{21}\ x\ 1313$	153385187670619,2411	$1{,}942 \cdot 10^{5}$	$8{,}235 \cdot 10^{-14}$	r = 0,27 µm	↔
$2^{22}\ x\ 1313$	306770375341238,4822	$1{,}942 \cdot 10^{5}$	$1{,}647 \cdot 10^{-13}$	r = 0,34 µm	↑
$2^{23}\ x\ 1313$	613540750682476,9643	$1{,}942 \cdot 10^{5}$	$3{,}294 \cdot 10^{-13}$	r = 0,43 µm	↑
$2^{24}\ x\ 1313$	1227081501364953,9286	$9{,}350 \cdot 10^{4}$	$6{,}588 \cdot 10^{-13}$	r = 0,54 µm	↓
$2^{25}\ x\ 1313$	2454163002729907,8572	$4{,}316 \cdot 10^{4}$	$1{,}318 \cdot 10^{-12}$	r = 0,68 µm	↓
$2^{26}\ x\ 1313$	4908326005459815,7144	$1{,}798 \cdot 10^{4}$	$2{,}635 \cdot 10^{-12}$	r = 0,86 µm	↓
$2^{27}\ x\ 1313$	9816652010919631,4288	$5{,}398 \cdot 10^{3}$	$5{,}270 \cdot 10^{-12}$	r =1,1 µm	↔
$2^{28}\ x\ 1313$	19633304021839262,8577	$5{,}398 \cdot 10^{3}$	$1{,}054 \cdot 10^{-11}$	r = 1,4 µm	↕
$2^{29}\ x\ 1313$	39266608043678525,7153	$2{,}251 \cdot 10^{3}$	$2{,}108 \cdot 10^{-11}$	r = 1,7 µm	↓
$2^{30}\ x\ 1313$	78533216087357051,4307	$6{,}776 \cdot 10^{2}$	$4{,}216 \cdot 10^{-11}$	r = 2,2 µm	↔
$2^{31}\ x\ 1313$	157066432174714102,8613	$6{,}776 \cdot 10^{2}$	$8{,}433 \cdot 10^{-11}$	r = 2,7 µm	↕
$2^{32}\ x\ 1313$	314132864349428205,7227	$2{,}843 \cdot 10^{2}$	$1{,}687 \cdot 10^{-10}$	r = 3,4 µm	↓
$2^{33}\ x\ 1313$	628265728698856411,4454	$8{,}759 \cdot 10^{1}$	$3{,}373 \cdot 10^{-10}$	r = 4,3 µm	↔
$2^{34}\ x\ 1313$	1256531457397712822,8908	$8{,}759 \cdot 10^{1}$	$6{,}746 \cdot 10^{-10}$	r = 5,4 µm	↕
$2^{35}\ x\ 1313$	2513062914795425645,7815	$3{,}842 \cdot 10^{1}$	$1{,}349 \cdot 10^{-9}$	r = 6,9 µm	↓
$2^{36}\ x\ 1313$	5026125829590851291,5630	$1{,}384 \cdot 10^{1}$	$2{,}698 \cdot 10^{-9}$	r = 8,6 µm	↓
$2^{37}\ x\ 1313$	10052251659181702583,1260	1,549	$5{,}397 \cdot 10^{-9}$	r = 11 µm	↔
$2^{38}\ x\ 1313$	20104503318363405166,2520	1,549	$1{,}079 \cdot 10^{-8}$	r = 14 µm	↑
$2^{39}\ x\ 1313$	40209006636726810332,5041	1,549	$2{,}159 \cdot 10^{-8}$	r = 17 µm	↕
$2^{40}\ x\ 1313$	80418013273453620665,0082	$1{,}260 \cdot 10^{-2}$	$4{,}318 \cdot 10^{-8}$	r = 22 µm	↔

$2^{41}\ x\ 1313$	1608360265469072413 30,0164	1,260 . 10^{-2}	8,635 . 10^{-8}	r = 27 μm	↑
$2^{42}\ x\ 1313$	32167205309381448266 0,0328	1,260 . 10^{-2}	1,727 . 10^{-7}	r = 35 μm	↑
$2^{43}\ x\ 1313$	6433441061876289653 20,0656	1,260 . 10^{-2}	3,454 . 10^{-7}	r = 44 μm	↑
$2^{44}\ x\ 1313$	12866882123752579306 40,1312	1,260 . 10^{-2}	6,908 . 10^{-7}	r = 55 μm	↑
$2^{45}\ x\ 1313$	25733764247505158612 80,2624	1,260 . 10^{-2}	1,382 . 10^{-6}	r = 69 μm	↑
$2^{46}\ x\ 1313$	51467528495010317225 60,5248	1,260 . 10^{-2}	2,763 . 10^{-6}	r = 87 μm	↕
$2^{47}\ x\ 1313$	102935056990020634451 21,0495	5,943 . 10^{-4}	5,527 . 10^{-6}	r = 0,11 mm	↔
$2^{48}\ x\ 1313$	205870113980041268902 42,0990	5,943 . 10^{-4}	1,105 . 10^{-5}	r = 0,14 mm	↑
$2^{49}\ x\ 1313$	411740227960082537804 84,1980	5,943 . 10^{-4}	2,211 . 10^{-5}	r = 0,17 mm	↑
$2^{50}\ x\ 1313$	823480455920165075609 68,3961	5,943 . 10^{-4}	4,421 . 10^{-5}	r = 0,22 mm	↑
$2^{51}\ x\ 1313$	1646960911840330151219 36,7921	5,943 . 10^{-4}	8,842 . 10^{-4}	r = 0,28 mm	↕
$2^{52}\ x\ 1313$	3293921823680660302438 73,5843	2,192 . 10^{-4}	1,768 . 10^{-4}	r = 0,35 mm	↓
$2^{53}\ x\ 1313$	6587843647361320604877 47,1686	3,162 . 10^{-5}	3,537 . 10^{-4}	r = 0,44 mm	↔
$2^{54}\ x\ 1313$	13175687294722641209754 94,3372	3,162 . 10^{-5}	7,074 . 10^{-4}	r = 0,55 mm	↑
$2^{55}\ x\ 1313$	26351374589445282419509 88,6744	3,162 . 10^{-5}	1,415 . 10^{-3}	r = 0,70 mm	↕
$2^{56}\ x\ 1313$	52702749178890564839019 77,3487	8,176 . 10^{-6}	2,830 . 10^{-3}	r = 0,88 mm	↔
$2^{57}\ x\ 1313$	105405498357781129678039 54,6975	8,176 . 10^{-6}	5,659 . 10^{-3}	r = 1,1 mm	↕
$2^{58}\ x\ 1313$	21081099.671556225935607909,3949	2,315 . 10^{-6}	1,132 . 10^{-2}	r = 1,4 mm	↔
$2^{59}\ x\ 1313$	421621993431124518712158 18,7898	2,315 . 10^{-6}	2,264 . 10^{-2}	r = 1,8 mm	↓
$2^{60}\ x\ 1313$	843243986862249037424316 37,5796	8,493 . 10^{-7}	4,527 . 10^{-2}	r = 2,2 mm	↓
$2^{61}\ x\ 1313$	1686487973724498074848632 75,1593	1,167 . 10^{-7}	9,055 . 10^{-2}	r = 2,8 mm	↔
$2^{62}\ x\ 1313$	3372975947448996149697265 50,3185	1,167 . 10^{-7}	1,811 . 10^{-1}	r = 3,5 mm	↑
$2^{63}\ x\ 1313$	6745951894897992299394531 00,6371	1,167 . 10^{-7}	3,622 . 10^{-1}	r = 4,4 mm	↕
$2^{64}\ x\ 1313$	13491903789795984598789062 01,2741	2,510 . 10^{-8}	7,244 . 10^{-1}	r = 5,6 mm	↔

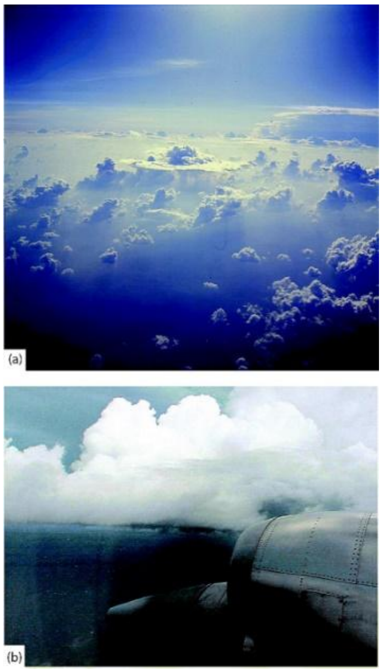
We can see that the process of prudent coalescence of water droplets follows a trend of decreasing alignment energy with local exceptions which become more frequent at higher steps. Tiny differences in the alignment energy, unfortunately hidden in the third column, are taken into account in the sixth column. Arrows shown in Tendency are directed according to (5a, 5b, 5c) from higher to lower energy. (See appendix 2) Water droplets thus find themselves in different circumstances: ↓ Coalescing is preferred. ↑ Breakup is preferred. ↕ Coalescing as well as breakup is preferred. ↔ Neither coalescing nor breakup is preferred. Anyway, the water droplet of about 0,36 g (equivalent in volume to a sphere of radius 4,4 mm) can be coalesced from water droplet $(H_2O)_{1313}$ in 63 steps. And water droplet of about 0,72 g (equivalent in volume to a sphere of radius 5,6 mm) can be coalesced in 64 steps. The largest till now recorded water droplet is 8.8 mm in diameter (equivalent in volume to a sphere of radius little less than 4,4 mmm). It was a raindrop coincidentally located in two places: at the cumulus congestus clouds spawned by biomass fires in the Amazon (September 1995) as well as at the base of a cumulus congestus cloud over the Marshall Islands (July 1999). [3]

6. CONCLUSION

In the light of alignment energy both attractive and repulsive tendency at coalescence of water droplets is recognized.

DEDICATION

To Amazon and Marshall Islands



(a) Photograph of cumulus congestus clouds spawned by biomass fires in the Amazon. (Photo: A. Rangno.)

(b) Photograph of cumulus congestus clouds over the Marshall Islands. (Photo: P. V. Hobbs.) [3]

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APPENDIX 1

For small x it holds:

$$(1+x)^a \approx 1 + ax. \qquad (1a)$$

Then for $x = \frac{\pi^2}{n^2}$ when n is large holds:

$$s(n) = n\left(2 - \frac{1}{\sqrt{1+\frac{\pi^2}{n^2}}}\right) = n\left(2 - \left(1+\frac{\pi^2}{n^2}\right)^{-\frac{1}{2}}\right) \approx n\left(2 - \left(1 - \frac{1}{2}\frac{\pi^2}{n^2}\right)\right) \approx n\left(1 + \frac{1}{2}\frac{\pi^2}{n^2}\right). \qquad (1b)$$

Ratio $\frac{R_{unaligned}}{R_{aligned}}$ is a measure of alignment energy. Applying the approximation

rounddown ($R_{unaligned}$)=$R_{aligned}$ we have, for instance at the 62th and 63th step, the next equality:

$$\frac{R^{62}_{unaligned}}{rounddown\,(R^{62}_{unaligned})} = \frac{R^{63}_{unaligned}}{rounddown\,(R^{63}_{unaligned})}. \qquad (2a)$$

Since

$$\frac{337297594744899614969726550{,}3185}{337297594744899614969726550} = \frac{2 \times 337297594744899614969726550{,}3185}{2 \times 337297594744899614969726550} \qquad (2b)$$

But with the help of the more exact calculation (5a, 5b, 5c) the next non-equation is given:

$$\frac{R^{62}_{unaligned}}{R^{62}_{aligned}} < \frac{R^{63}_{unaligned}}{R^{63}_{aligned}}. \qquad (2c)$$

Since

$$\frac{337297594744899614969726550{,}3185}{337297594744899614969726550 + 1{,}46 \,.\, 10^{-26}} < \frac{2 \times 337297594744899614969726550{,}3185}{2 \times 337297594744899614969726550 + 7{,}3 \,.10^{-27}} \qquad (2d)$$

Citation: *Janez Špringer (2022) "Coalescence of Water Droplets in Light of Alignment Energy" International Journal of Advanced Research in Physical Science (IJARPS) 9(7), pp.1-6, 2022.*