

Some Notes about the things I encountered

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Notation

If E is an Elliptic Curve defined over a finite field of characteristic p , we write $E^{(p)}$ for the curve defined by the equations of E after replacing all coefficients by their p -th power. Similarly, for an isogeny $\phi : E \rightarrow E'$, write $\phi^{(p)} : E^{(p)} \rightarrow E'^{(p)}$ for the isogeny defined by the polynomials of ϕ after replacing all coefficients by their p -th power. Furthermore, for a point $P = (x : y : z) \in \mathbb{P}^2$ write $P^{(p)} := (x^p : y^p : z^p)$. Finally, for a set of points or endomorphisms S write $S^{(p)} := \{s^{(p)} \mid s \in S\}$. Note that

$$\begin{aligned} \cdot^{(p)} : \mathbf{Ell} &\rightarrow \mathbf{Ell}, & E &\mapsto E^{(p)} \\ \mathrm{Hom}_{\mathbf{Ell}}(E, E') &\ni \phi \rightarrow \phi^{(p)} \end{aligned}$$

is a covariant endofunctor on the category \mathbf{Ell} of Elliptic Curves defined over $\bar{\mathbb{F}}_p$ and their isogenies.

Sometimes, we abuse terminology and speak of Elliptic Curves when we mean isomorphism classes of Elliptic Curves.

Many examples will be over \mathbb{F}_{101^2} . Let $p = 101$ and $q = p^2$. We usually use the generator $\alpha \in \mathbb{F}_q$ with minimal polynomial $x^2 + 97x + 2$.

1 Example - The cases I, II and III

1.1 Case I

Finding examples of case I is trivial - just take a curve E with $j(E) \in \mathbb{F}_p$. Then clearly $E^{(p)} = E$ and so also $E_0^{(p)} = E_0$ (since $\cdot^{(p)}$ maps the path $E \rightarrow E_0$ to $E = E^{(p)} \rightarrow E_0^{(p)}$).

Furthermore, it is easy to see that there are a lot of curve E such that the associated E_0 is defined over \mathbb{F}_p (and we are again in case I).

1.2 Case II

Here I was not quite sure if it even occurs. As it turns out, it does. Consider E with $j(E) = 17\alpha + 45$. Then $[\mathcal{O}_K : \mathbb{Z}[\pi]] = 2^3$ so E lies on the crater of the 3-isogeny graph. However there is a 3-isogeny $E \rightarrow E^{(p)}$ since $j(E^{(p)}) = j(E)^p = 84\alpha + 12$. In fact, in

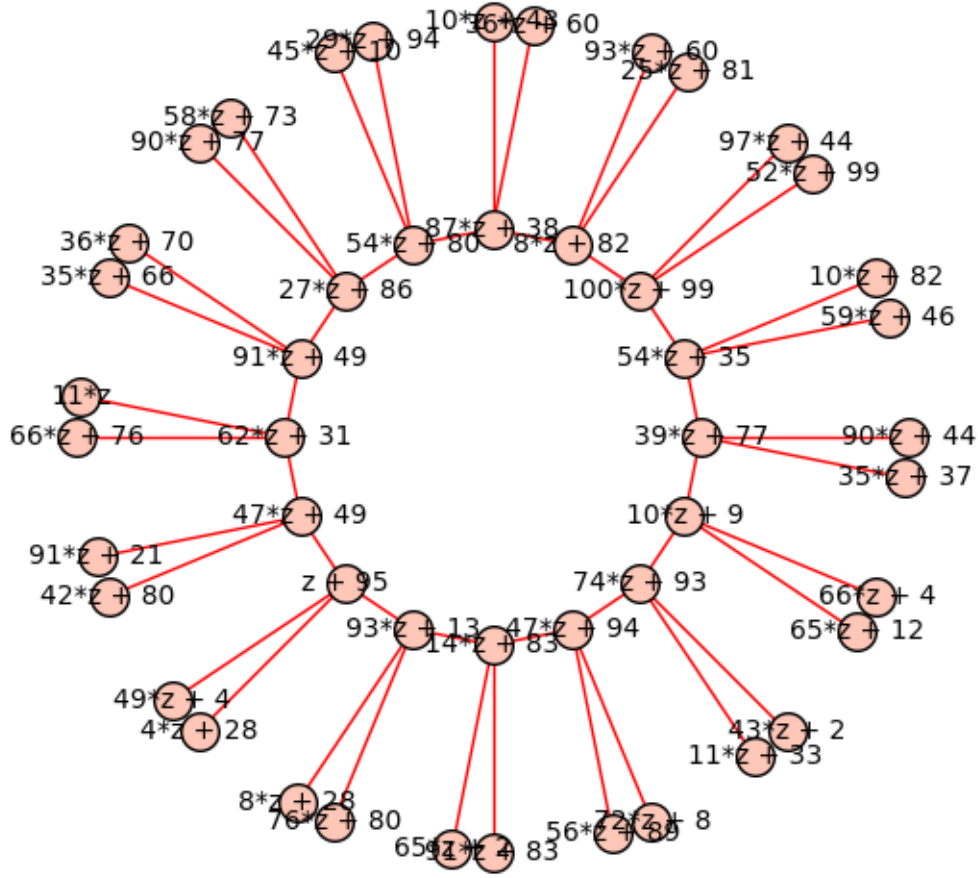


Figure 1: A 3-isogeny vulcano over $\mathbb{F}_{101^2} = \mathbb{F}_{101}[\alpha]$ that satisfies case II (in the plot have $z = \alpha$). Note that e.g. $(39\alpha + 77)^{101} = 62\alpha + 31$.

this case, the crater consists only of E and $E^{(p)}$. For a more interesting example, see Figure 1.

Further, when we consider the path $E = E_0 \rightarrow \dots \rightarrow E_n = E^{(p)}$ on the crater, there are more or less two possibilities for the $\cdot^{(p)}$ conjugate path¹.

- It could be that the conjugate of $E_i \rightarrow E_{i+1}$ is the dual of $E_{n-i-1} \rightarrow E_{n-i}$, hence we just go the path $E \rightarrow \dots \rightarrow E^{(p)}$ backwards.
- It could be that the conjugate of $E_i \rightarrow E_{i+1}$ is $E_{n+i} \rightarrow E_{n+i+1}$, where

$$E_0, \dots, E_n, E_{n+1}, \dots, E_{n+m} = E_0$$

is the cycle along the whole crater.

Both cases have interesting consequences:

¹Remember that $\cdot^{(p)}$ is functorial, hence we can also apply to isogenies $E_i \rightarrow E_{i+1}$

First case The fact that the conjugate of $E_i \rightarrow E_{i+1}$ is the dual of $E_{n-i-1} \rightarrow E_{n-i}$ implies that $E_i^{(p)} = E_{n-i}$. In particular, if n is even, we find that $E_{n/2}$ is defined over \mathbb{F}_p .

Note that we have

Proposition 1.1. *Let E be an ordinary Elliptic Curve defined over a finite field of characteristic p .*

- $\text{End}(E)$ has an element of norm p iff $j(E) \in \mathbb{F}_p$.
- $\text{End}(E)$ has a nontrivial element (i.e. $\neq \pm p$) of norm p^2 iff $j(E) \in \mathbb{F}_{p^2}$.

Proof. The directions \Leftarrow is clear, as the norm of the q -th power Frobenius endomorphism is q .

For the direction \Rightarrow , assume there is an element $\alpha \in \text{End}(E)$ with $N(\alpha) = p$. If α is inseparable (as isogeny), then we have that it factors through the p -th power Frobenius endomorphism π , and thus $\alpha = \lambda \circ \pi$ for an isomorphism $\lambda : E^{(p)} \rightarrow E$. Thus $j(E^{(p)}) = j(E)$.

On the other hand, if α is separable, it must have kernel of size p , so $\ker(\alpha) = E[p]$ since $\#E[p] = p$ (E is ordinary). Thus $\ker(\alpha) \subseteq \ker([p])$ and we see that $[p]$ factors through α as $[p] = \psi \circ \alpha$. Now have that $\deg(\psi) = p = p^2 / \deg(\alpha)$ and clearly ψ is inseparable. The claim follows as above.

For the second point, assume $\alpha \in \text{End}(E)$ has norm $N(\alpha) = p^2$ and $\alpha \neq \pm p$. If α is purely inseparable, we are done. If α is separable, its kernel must be $E[p^2]$ and so it factors through $[p^2]$. Since $[p^2]$ has inseparability degree p^2 , we see that $[p^2] = \pi^2 \circ \alpha$ where π is the p -th power Frobenius morphism. Since α is an endomorphism of E , find $\pi^2 : E \rightarrow E$, thus $j(E) \in \mathbb{F}_{p^2}$.

Finally, if α has inseparability degree p , then its kernel must be $E[p]$ and so $\alpha = \beta \circ \pi$ where $\beta : E^{(p)} \rightarrow E$ is separable with kernel $E^{(p)}[p]$. However, by the uniqueness of the separable isogeny with kernel $E^{(p)}[p]$, we know that (up to isomorphism) also $[p]$ is $\beta \circ \pi$. Thus $\alpha = \pm p$, a contradiction. \square

In particular, it follows that either all or none of the curves on the crater of the vulcano have $j(E) \in \mathbb{F}_p$.

Proposition 1.2. *Let $[\mathfrak{b}] \in \text{Cl}(\mathcal{O})$ where $\mathcal{O} = \text{End}(E)$ for an ordinary Elliptic Curve E/\mathbb{F}_{p^2} such that $[\mathfrak{b}].E = E^{(p)}$. Then $[\mathfrak{b}]^2 = [(1)]$.*

Proof. We recall the definition of the class group action in the case $[\mathfrak{b}].E^{(p)}$. For an ideal $\mathfrak{b}' \leq \text{End}(E^{(p)})$, have by definition

$$[\mathfrak{b}'].E^{(p)} = E^{(p)} / E^{(p)}[\mathfrak{b}'] = E^{(p)} / \bigcap_{\beta \in \mathfrak{b}'} \ker(\beta)$$

However, \mathfrak{b} is an ideal in $\text{End}(E)$, which is only isomorphic to $\text{End}(E^{(p)})$. Since $\text{End}^0(E)$ is a quadratic imaginary number field, it has one nontrivial field automorphism, and thus

the isomorphism $\text{End}(E) \cong \text{End}(E^{(p)})$ is not unique. But there is a unique canonical isomorphism, i.e. an isomorphism that is induced by an (equivalently any) isogeny $\phi : E \rightarrow E^{(p)}$ as

$$\Phi_* : \text{End}(E) \rightarrow \text{End}(E^{(p)}), \quad \alpha \mapsto \frac{1}{\deg(\phi)} \phi \circ \alpha \circ \hat{\phi}$$

This is the isomorphism we use, i.e. we say

$$E^{(p)}[\mathfrak{b}] = E^{(p)}[\Phi_*(\mathfrak{b})] \quad \text{and} \quad [\mathfrak{b}].E^{(p)} = [\Phi_*(\mathfrak{b})].E^{(p)} = E^{(p)}/E^{(p)}[\mathfrak{b}]$$

Now let $\phi : E \rightarrow E/E[\mathfrak{b}] = E^{(p)}$ be a separable isogeny with kernel $E[\mathfrak{b}]$ (by choosing the representative \mathfrak{b} of $[\mathfrak{b}] \in \text{Cl}(\mathcal{O})$ correspondingly, we can assume that). We have

$$\ker(\phi^{(p)}) = E[\mathfrak{b}]^{(p)} = \bigcap_{\beta \in \mathfrak{b}} \ker(\beta)^{(p)} = \bigcap_{\beta \in \mathfrak{b}} \ker(\beta^{(p)}) = \bigcap_{\beta \in \mathfrak{b}^{(p)}} \ker(\beta)$$

Now note that the Frobenius isogeny $\pi : E \rightarrow E^{(p)}$, $P \mapsto P^{(p)}$ induces the canonical isomorphism $\text{End}(E) \rightarrow \text{End}(E^{(p)})$ and so the image of \mathfrak{b} under that isomorphism is $\mathfrak{b}' = \mathfrak{b}^{(p)} \leq \text{End}(E^{(p)})$. Thus

$$\bigcap_{\beta \in \mathfrak{b}^{(p)}} \ker(\beta) = \bigcap_{\beta \in \mathfrak{b}'} \ker(\beta) = E^{(p)}[\mathfrak{b}'] = E^{(p)}[\mathfrak{b}]$$

So by the uniqueness of the image curve for an isogeny with fixed kernel yields that $E = \text{im}(\phi^{(p)}) = [\mathfrak{b}].E^{(p)}$. Thus $[\mathfrak{b}]^2.E = [\mathfrak{b}].E^{(p)} = E$ and since the class group action is free, we see that $[\mathfrak{b}]^2 = [(1)]$. \square

From this we get the

Corollary 1.3. *Assume that $E = E_0 \rightarrow E_1 \rightarrow \dots \rightarrow E_n = E$ is the cycle once around the crater (and $j(E) \in \mathbb{F}_{p^2} \setminus \mathbb{F}_p$). If $E^{(p)} = E_i$ then n is even and $i = n/2$, i.e. $E^{(p)}$ is on the other side of the crater².*

Proof. If l does not split in \mathcal{O}_K , then the crater has at most two elements and this is trivial. So assume $(l) = \mathfrak{l}_1 \mathfrak{l}_2$. It is known that then the action of $[\mathfrak{l}_1]$ resp. $[\mathfrak{l}_2]$ corresponds to walking around the crater in one direction resp. the other. So wlog $[\mathfrak{l}_1].E_i = E_{i+1}$.

Now assume that $E^{(p)} = E_i$, so $[\mathfrak{b}].E = E_i = [\mathfrak{l}_1]^i.E$. Since the action is free, it follows that $[\mathfrak{b}] = [\mathfrak{l}_1]^i$. By the previous theorem, we have now $[\mathfrak{l}_1]^{2i} = [\mathfrak{b}]^2 = [(1)]$ and so $[\mathfrak{l}_1]^{2i}.E = E_{2i} = E$. Thus $i = n/2$ and the claim follows. \square

In particular, the path between E and $E^{(p)}$ is likely to have length $\omega(\log(p))$, since the crater is usually large. This is displayed e.g. Figure 1.

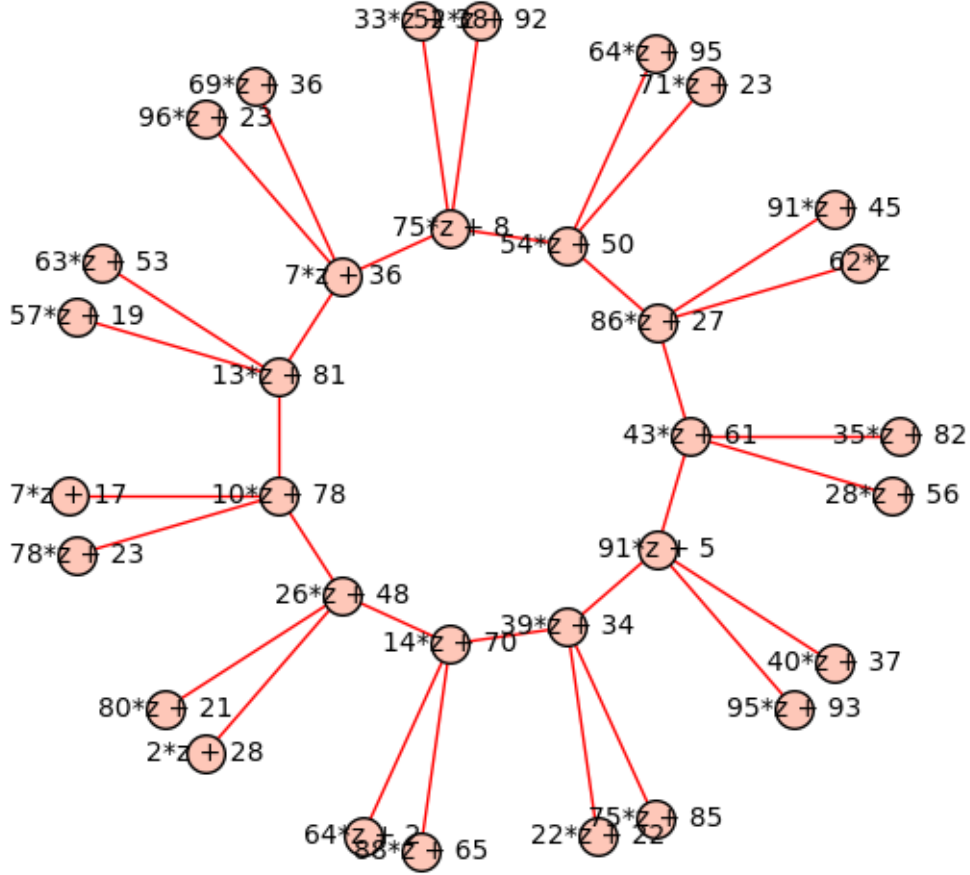


Figure 2: A 3-isogeny volcano over $\mathbb{F}_{101^2} = \mathbb{F}_{101}[\alpha]$ that satisfies case III (in the plot have $z = \alpha$).

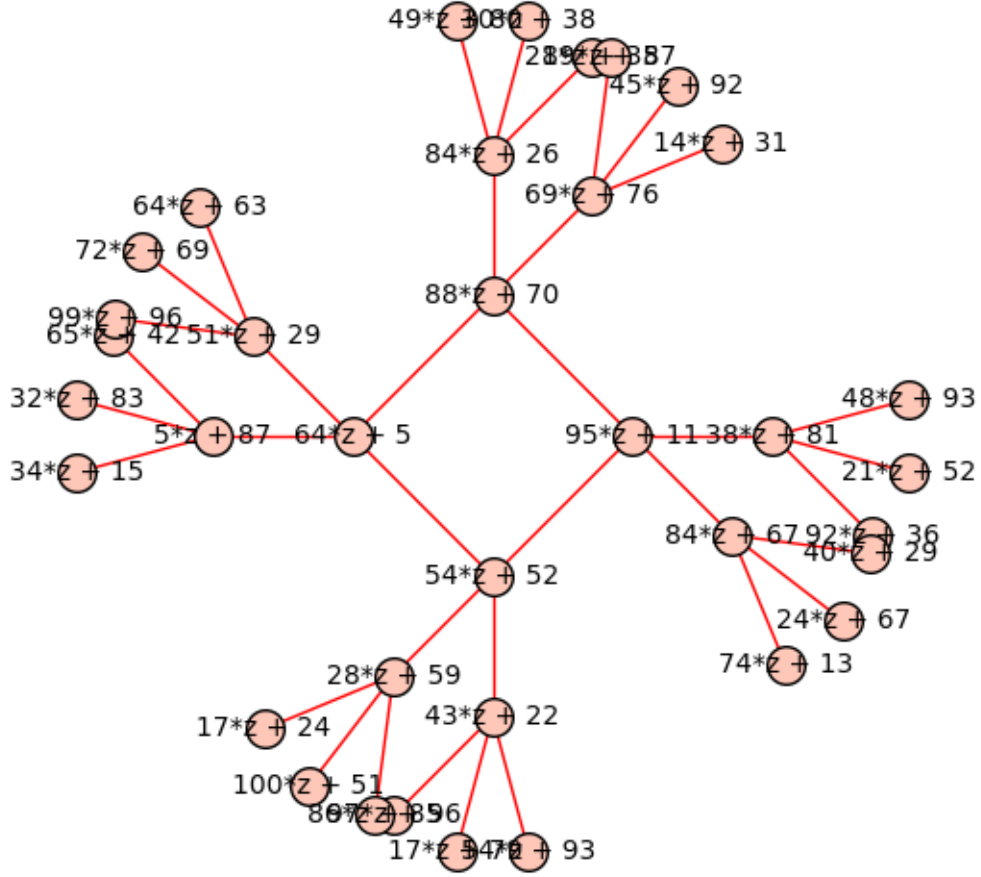


Figure 3: A 3-isogeny volcano over $\mathbb{F}_{101^2} = \mathbb{F}_{101}[\alpha]$ that satisfies case III (in the plot have $z = \alpha$).

1.3 Case III

We give the example displayed in Figure 3. Consider E with $j(E) = 64\alpha + 5$. Then $j(E^{(p)}) = j(E)^p = 37\alpha + 59$. However, we have that E lies on the crater, together with curve of j -invariants

$$88\alpha + 70, 54\alpha + 52, 95\alpha + 11$$

Hence there is no 3-isogeny path from E to $E^{(p)}$. Note that $[\mathcal{O}_K : \mathbb{Z}[\pi]] = 2^2 \cdot 3^2$ but $[\mathcal{O}_K : \text{End}(E)] = 2^2$, which shows that E lies on the crater.

Now we want to have a closer look onto the class group action in this case. Have $d(\text{End}(E)) = -320$, so $K = \mathbb{Q}(\sqrt{-5})$ and $d(\mathcal{O}_K) = -5$. Hence, we have $\text{End}(E) \cong \mathbb{Z}[4\sqrt{-5}]$ and $\mathcal{O}_K \cong \mathbb{Z}[\sqrt{-5}]$.

Sage tells us that $h(\mathcal{O}_K) = 2$ and $h(\text{End}(E)) = 8$. With this, we can already see that

$$64\alpha + 5, 88\alpha + 70, 54\alpha + 52, 95\alpha + 11$$

and

$$(64\alpha + 5)^p, (88\alpha + 70)^p, (54\alpha + 52)^p, (95\alpha + 11)^p$$

is the set of j -invariants of all Elliptic Curves with endomorphism ring $\cong \text{End}(E)$. On this set, $\text{Cl}(\mathbb{Z}[4\sqrt{-5}])$ then acts freely and transitively. Now it would be of course interesting to find out how $\text{Cl}(\mathbb{Z}[4\sqrt{-5}])$ really looks like.

2 Properties of the endomorphism ring vs the cases

Let E/\mathbb{F}_{p^2} be an ordinary Elliptic Curve and write $\mathcal{O} := \text{End}(E), K := \text{End}(E) \otimes \mathbb{Q}$. Let π be the $q = p^2$ -th power Frobenius endomorphism and let t be the trace of Frobenius. Assume $p \neq 2$.

Lemma 2.1. *Have $(p) = (p, \pi)(p, \pi - t)$.*

Proof. Have

$$(p, \pi)(p, \pi - t) = (p^2, p\pi, p\pi - pt, \pi^2 - t\pi) = (p^2, pt, p\pi, -p^2) = (up^2 + vtp, \dots) = (p)$$

where $up + vt = 1$ (note that $t \perp p$ since E is ordinary). \square

Proposition 2.2. *Let E/\mathbb{F}_{p^2} be an ordinary Elliptic Curve. Then $p = p_1 p_2$ in $\text{End}(E)$.*

3 Example - The ordinary endomorphism ring

The information in this section is all known material - I just wanted to understand properly how one can compute the endomorphism ring, and what problems occur.

Consider the finite field

$$\mathbb{F}_q = \mathbb{F}_{37^2} = \mathbb{F}_{37} + \alpha\mathbb{F}_{37}$$

²Note that this does not hold if $E, E^{(p)}$ are not in the same crater, see Figure 2.

$j(E)$	$h(\text{End}(E))$	$[\mathcal{O}_K : \mathbb{Z}[\phi]]$
α	36	6
$4\alpha + 99$	64	2

Table 1: Table of class numbers of $\text{End}(E)$ for Elliptic Curves $E/\mathbb{F}_{101^2} = \mathbb{F}_{101}[\alpha]$.

where $\alpha^2 + 33\alpha + 2 = 0$. Further, consider the Elliptic Curve E/\mathbb{F}_q with j -invariant 3α , given by

$$E : y^2 = x^3 + (15\alpha + 17)x + (5\alpha + 3)$$

Then we find that the q -th power Frobenius endomorphism π satisfies the minimal equation

$$\pi^2 + 47\pi + 1369$$

and in particular, its trace is -47 . Hence, the number field $K := \mathcal{O} \otimes \mathbb{Q}$ where $\mathcal{O} = \text{End}(E)$ contains $\sqrt{47^2 - 4 \cdot 1369} = \sqrt{-3^3 \cdot 11^2}$. We observe that $K = \mathbb{Q}(\sqrt{-3})$ and has discriminant -3 . Furthermore the ring of integers is $\mathcal{O}_K = \mathbb{Z}[\frac{1}{2}(1 + \sqrt{-3})]$.

Knowing the number field, we want to find the endomorphism ring. First, observe that the Frobenius order $\mathbb{Z}[\pi]$ has conductor 33. Now consider the endomorphism

$$\phi := 2\pi + 47$$

The advantage is that we can evaluate ϕ on points of E , but evaluating $\pi + 47/2$ is not so easy. Clearly $[\mathbb{Z}[\pi] : \mathbb{Z}[\phi]] = 2$ and so $\mathbb{Z}[\phi]$ has conductor 66.

Torsion points

In order to find whether $\phi/n \in \mathcal{O}$, we factor $66 = 2 \cdot 3 \cdot 11$ and compute the corresponding torsion groups. This turns out to be quite difficult.

Assume $\mathbb{F}_{37^{12}} = \mathbb{F}_{37}[\beta]$ with

$$\text{MiPo}_{\mathbb{F}_{37}}(\beta) = x^{12} + 4x^7 + 31x^6 + 10x^5 + 23x^4 + 18x^2 + 33x + 2$$

Then $E[2]$ is generated by

$$P_1 = (11\beta^{11} + 19\beta^{10} + \beta^9 + 27\beta^8 + 8\beta^7 + 16\beta^6 + 17\beta^5 + 32\beta^4 + 12\beta^3 + 14\beta^2 + 24\beta + 32 : 0 : 1)$$

$$Q_1 = (15\beta^{11} + 7\beta^{10} + 33\beta^9 + 11\beta^8 + 6\beta^7 + 12\beta^6 + 26\beta^5 + 7\beta^4 + 33\beta^3 + 25\beta^2 + 8\beta + 19 : 0 : 1)$$

Further $E[3]$ is generated by

$$P_2 = (19\beta^{11} + 34\beta^{10} + 3\beta^9 + 29\beta^8 + 7\beta^7 + 3\beta^6 + 18\beta^5 + 21\beta^4 + 23\beta^3 + 30\beta^2 + 23\beta + 25 : 6\beta^{11} + 25\beta^{10} + 4\beta^9 + 13\beta^8 + 10\beta^7 + 23\beta^6 + 20\beta^5 + 30\beta^4 + 24\beta^3 + 6\beta^2 + 17\beta + 5 : 1)$$

$$Q_2 = (31\beta^{11} + 24\beta^{10} + 35\beta^9 + 32\beta^8 + 2\beta^7 + 10\beta^6 + 23\beta^5 + 35\beta^4 + 22\beta^3 + 13\beta^2 + 12\beta + 12 : 18\beta^{11} + 2\beta^{10} + 32\beta^9 + 26\beta^8 + 17\beta^7 + 5\beta^6 + 19\beta^5 + 31\beta^4 + 31\beta^3 + \beta^2 + 22\beta + 1 : 1)$$

For $E[11]$ we must even go to the extension degree 110. So assume $\mathbb{F}_{37^{220}} = \mathbb{F}_{37}[\gamma]$. Then $E[11]$ is generated by P_3 and Q_3 . For the values of $\text{MiPo}_{\mathbb{F}_{37}}(\gamma)$ and P_3, Q_3 see Section 4.

Now we can compute $\phi(P_1), \phi(Q_1), \phi(P_2), \phi(Q_2), \phi(P_3), \phi(Q_3)$ and see that none of them is zero. Since $\deg(\phi) = [\mathcal{O} : \mathbb{Z}[\phi]] \mid [\mathcal{O}_K : \mathbb{Z}[\phi]] = 2 \cdot 3 \cdot 11$, we see that the kernel of ϕ is trivial. Thus no ϕ/n is contained in \mathcal{O} . Therefore we see that

$$\mathcal{O} \cap \mathbb{Z}[\sqrt{D}] = \mathbb{Z}[\phi]$$

The inclusion \supseteq is clear, and for the other direction, note that $\mathcal{O} \cap \mathbb{Z}[\sqrt{D}] = \mathbb{Z} + t\sqrt{D}\mathbb{Z}$ and $\mathbb{Z}[\phi] = \mathbb{Z} + s\sqrt{D}\mathbb{Z}$. Since $\mathbb{Z}[\phi] \subseteq \mathcal{O} \cap \mathbb{Z}[\phi]$ find thus $t \mid s$. Now observe that by choice of ϕ , have $\phi^2 \in \mathbb{Z}$ and so $\phi = s\sqrt{D}$. However, $\phi/\frac{s}{t} = t\sqrt{D} \in \mathcal{O}$. By the above, it follows that $\frac{s}{t} = 1$, i.e. $s = t$.

The index $[\mathcal{O} : \mathbb{Z}[\phi]]$

From the consideration of the torsion points, we see that $\mathcal{O} \cap \mathbb{Z}[\sqrt{D}] = \mathbb{Z}[\phi]$. However, since $[\mathcal{O}_K : \mathbb{Z}[\sqrt{D}]] \leq 2$, we deduce that $[\mathcal{O} : \mathbb{Z}[\phi]] \leq 2$ and so

$$\mathcal{O} = \mathbb{Z}[\pi]$$

4 P_3 and Q_3

The minimal polynomial of γ is

$$\begin{aligned} & x^{220} + 31x^{219} + 13x^{218} + 21x^{217} + 23x^{216} + 9x^{215} \\ & + 2x^{214} + 35x^{212} + 10x^{211} + 29x^{210} + 25x^{209} + 20x^{208} \\ & + 17x^{207} + 30x^{206} + 5x^{205} + 15x^{204} + 11x^{203} + 10x^{202} \\ & + 11x^{201} + 32x^{200} + 5x^{199} + 28x^{198} + 7x^{197} + 13x^{196} \\ & + 10x^{195} + 32x^{194} + 17x^{193} + 19x^{192} + 36x^{191} \\ & + 17x^{190} + 31x^{189} + 14x^{188} + 6x^{187} + 30x^{186} + 8x^{185} \\ & + 22x^{184} + 2x^{183} + 9x^{182} + 11x^{181} + 6x^{180} + 23x^{179} \\ & + 14x^{178} + 36x^{177} + 16x^{176} + 34x^{175} + 14x^{174} \\ & + 33x^{173} + 14x^{172} + 7x^{171} + 36x^{170} + 18x^{169} + 27x^{168} \\ & + 5x^{167} + 31x^{166} + 6x^{165} + 15x^{164} + 14x^{163} + 17x^{162} \\ & + 7x^{161} + 16x^{160} + 6x^{159} + 29x^{158} + 11x^{157} + 8x^{156} \\ & + 15x^{155} + 20x^{154} + 17x^{153} + 7x^{152} + 8x^{151} + 6x^{150} \\ & + 12x^{149} + 36x^{148} + 7x^{147} + 3x^{146} + 25x^{145} + 13x^{144} \\ & + 6x^{143} + 17x^{142} + 22x^{141} + 9x^{140} + 18x^{139} + 36x^{138} \\ & + x^{137} + 6x^{136} + 36x^{135} + 33x^{134} + 32x^{133} + 35x^{132} \\ & + 33x^{131} + 7x^{130} + 3x^{129} + 7x^{128} + 20x^{127} + 31x^{126} \\ & + 26x^{125} + 6x^{124} + 9x^{123} + 10x^{122} + 25x^{121} + 33x^{120} \\ & + 33x^{119} + 30x^{118} + 34x^{117} + 22x^{116} + 8x^{115} + 10x^{114} \\ & + 36x^{113} + 26x^{112} + 8x^{111} + 33x^{110} + 30x^{109} + 11x^{108} \\ & + 14x^{107} + 22x^{106} + 26x^{105} + 11x^{104} + 35x^{103} \end{aligned}$$

$$\begin{aligned}
& + 34x^{102} + 33x^{101} + 27x^{100} + 14x^{99} + 31x^{98} + 24x^{97} \\
& + x^{96} + 6x^{95} + 36x^{93} + 32x^{92} + 18x^{91} + 36x^{90} + 3x^{89} \\
& + 22x^{88} + 36x^{87} + 6x^{86} + 20x^{85} + 25x^{84} + 8x^{82} \\
& + 34x^{81} + 7x^{80} + 25x^{79} + 21x^{78} + 17x^{77} + 29x^{76} \\
& + 5x^{75} + 19x^{74} + 19x^{73} + 8x^{72} + 8x^{71} + 26x^{70} \\
& + 7x^{69} + 27x^{68} + 10x^{67} + 31x^{66} + 4x^{65} + 29x^{64} \\
& + 36x^{62} + 3x^{61} + 27x^{60} + 13x^{59} + 23x^{58} + 33x^{57} \\
& + 14x^{56} + 19x^{55} + 12x^{54} + 20x^{53} + 32x^{52} + 18x^{51} \\
& + 20x^{49} + 20x^{48} + x^{47} + 17x^{46} + 16x^{45} + 4x^{44} \\
& + 12x^{43} + 7x^{42} + 34x^{41} + 9x^{40} + 16x^{39} + 10x^{38} \\
& + 25x^{37} + 10x^{36} + 10x^{35} + 28x^{34} + 33x^{33} + 22x^{32} \\
& + 24x^{31} + 33x^{30} + 6x^{29} + 8x^{28} + 8x^{27} + 16x^{26} \\
& + 31x^{25} + 7x^{24} + 26x^{23} + 36x^{22} + 29x^{21} + 36x^{20} \\
& + 7x^{19} + x^{18} + 26x^{17} + 18x^{16} + 23x^{15} + 10x^{14} \\
& + 4x^{13} + x^{12} + 24x^{11} + 25x^{10} + 34x^9 + 33x^8 \\
& + 33x^7 + 8x^6 + 12x^5 + x^4 + 15x^3 + 27x^2 + 9x + 2
\end{aligned}$$

P_3 is given by

$$\begin{aligned}
& (23z^{220} + 5z^{219} + 26z^{218} + 27z^{217} + 26z^{216} \\
& + 12z^{215} + 11z^{214} + 10z^{213} + 29z^{212} + 9z^{211} + 16z^{210} + 24z^{209} + 18z^{208} \\
& + 11z^{207} + 11z^{206} + 6z^{205} + 24z^{204} + 3z^{203} + 34z^{202} + 18z^{201} + 17z^{200} \\
& + 9z^{199} + 26z^{198} + 2z^{197} + 31z^{196} + 7z^{195} + 15z^{194} + 11z^{193} + 15z^{192} \\
& + 28z^{191} + 13z^{190} + 6z^{189} + 7z^{188} + 28z^{187} + 9z^{186} + 9z^{185} + 7z^{184} \\
& + 27z^{183} + 36z^{182} + 35z^{181} + 30z^{180} + 32z^{179} + 16z^{178} + 15z^{177} + 16z^{176} \\
& + 9z^{175} + 21z^{174} + 6z^{173} + 15z^{172} + 3z^{171} + 25z^{170} + 23z^{169} + z^{168} \\
& + 8z^{167} + 34z^{166} + 14z^{165} + 12z^{164} + 20z^{163} + 4z^{162} + 9z^{161} + z^{160} \\
& + 25z^{159} + 16z^{158} + z^{157} + 21z^{156} + 10z^{155} + 7z^{154} + 13z^{153} + 32z^{152} \\
& + 31z^{151} + 17z^{150} + 24z^{149} + 26z^{148} + 28z^{147} + 27z^{146} + 4z^{145} + 5z^{144} \\
& + 14z^{143} + 26z^{142} + 10z^{141} + 14z^{140} + 19z^{139} + 20z^{138} + 18z^{137} + 16z^{136} \\
& + 11z^{135} + 23z^{134} + 35z^{133} + 22z^{132} + 31z^{131} + 34z^{130} + 17z^{129} + z^{128} \\
& + 15z^{127} + 2z^{126} + 22z^{125} + 27z^{124} + 6z^{123} + 10z^{122} + 7z^{121} + 4z^{120} \\
& + 26z^{119} + z^{118} + 32z^{117} + z^{116} + 32z^{115}
\end{aligned}$$

$$\begin{aligned}
& + 29*z^{220}_{114} + 32*z^{220}_{113} + 18*z^{220}_{112} + 3*z^{220}_{111} \\
& + 28*z^{220}_{110} + 20*z^{220}_{109} + 17*z^{220}_{108} + 17*z^{220}_{107} \\
& + 32*z^{220}_{106} + 32*z^{220}_{105} + 26*z^{220}_{104} + 24*z^{220}_{103} \\
& + 17*z^{220}_{102} + 8*z^{220}_{101} + 3*z^{220}_{100} + 2*z^{220}_{99} \\
& + 16*z^{220}_{98} + 29*z^{220}_{97} + 19*z^{220}_{96} + 27*z^{220}_{95} \\
& + 4*z^{220}_{94} + 29*z^{220}_{93} + 24*z^{220}_{92} + 19*z^{220}_{91} \\
& + 2*z^{220}_{90} + 2*z^{220}_{89} + 32*z^{220}_{88} + 23*z^{220}_{87} \\
& + 32*z^{220}_{86} + 15*z^{220}_{85} + 24*z^{220}_{84} + 36*z^{220}_{83} \\
& + 29*z^{220}_{82} + 18*z^{220}_{81} + 2*z^{220}_{80} + z^{220}_{79} \\
& + 33*z^{220}_{78} + 34*z^{220}_{77} + 4*z^{220}_{76} + 11*z^{220}_{75} \\
& + 21*z^{220}_{74} + 15*z^{220}_{73} + 10*z^{220}_{72} + 24*z^{220}_{71} \\
& + 22*z^{220}_{70} + 22*z^{220}_{69} + 31*z^{220}_{68} + 32*z^{220}_{67} \\
& + 28*z^{220}_{66} + z^{220}_{65} + 17*z^{220}_{64} + 13*z^{220}_{63} \\
& + 32*z^{220}_{62} + 20*z^{220}_{61} + 32*z^{220}_{60} + 21*z^{220}_{59} \\
& + 34*z^{220}_{58} + 11*z^{220}_{57} + 29*z^{220}_{56} + 12*z^{220}_{55} \\
& + 22*z^{220}_{54} + 11*z^{220}_{53} + 36*z^{220}_{52} + 35*z^{220}_{51} \\
& + 19*z^{220}_{50} + 35*z^{220}_{49} + 8*z^{220}_{48} + 16*z^{220}_{47} \\
& + 16*z^{220}_{46} + 27*z^{220}_{45} + 32*z^{220}_{44} + 12*z^{220}_{43} \\
& + 15*z^{220}_{42} + 6*z^{220}_{41} + 36*z^{220}_{40} + 27*z^{220}_{39} \\
& + 17*z^{220}_{38} + 20*z^{220}_{37} + 33*z^{220}_{36} + 34*z^{220}_{35} \\
& + 34*z^{220}_{34} + 3*z^{220}_{33} + 12*z^{220}_{32} + 12*z^{220}_{31} \\
& + 12*z^{220}_{30} + 5*z^{220}_{29} + 10*z^{220}_{28} + 13*z^{220}_{27} \\
& + 36*z^{220}_{26} + 16*z^{220}_{25} + 16*z^{220}_{24} + 15*z^{220}_{23} \\
& + 36*z^{220}_{22} + 18*z^{220}_{21} + 13*z^{220}_{20} + 26*z^{220}_{19} \\
& + 25*z^{220}_{18} + 21*z^{220}_{17} + 35*z^{220}_{16} + 3*z^{220}_{14} \\
& + 31*z^{220}_{13} + 8*z^{220}_{12} + 7*z^{220}_{11} + 10*z^{220}_{10} \\
& + 10*z^{220}_9 + 6*z^{220}_8 + 5*z^{220}_7 + 33*z^{220}_6 \\
& + 6*z^{220}_5 + 4*z^{220}_4 + 31*z^{220}_3 + 27*z^{220}_2 + 27*z^{220} + 14 \\
& : 8*z^{220}_{219} + 17*z^{220}_{218} + 27*z^{220}_{217} + 14*z^{220}_{216} \\
& + 6*z^{220}_{215} + 19*z^{220}_{214} + 18*z^{220}_{213} + 6*z^{220}_{212} \\
& + 30*z^{220}_{211} + 24*z^{220}_{210} + 33*z^{220}_{209} + 19*z^{220}_{208} \\
& + 27*z^{220}_{207} + 16*z^{220}_{206} + 24*z^{220}_{205} + 3*z^{220}_{204} \\
& + 4*z^{220}_{203} + 25*z^{220}_{202} + 29*z^{220}_{201} + 31*z^{220}_{200} \\
& + 23*z^{220}_{199} + 7*z^{220}_{198} + 28*z^{220}_{197} + 4*z^{220}_{196} \\
& + 26*z^{220}_{195} + 36*z^{220}_{194} + 18*z^{220}_{193} + 24*z^{220}_{192} \\
& + 29*z^{220}_{191} + 25*z^{220}_{190} + 23*z^{220}_{189} + 14*z^{220}_{188} \\
& + 33*z^{220}_{187} + 19*z^{220}_{186} + 14*z^{220}_{184} + 21*z^{220}_{183} \\
& + 10*z^{220}_{182} + 13*z^{220}_{181} + 21*z^{220}_{180} + 24*z^{220}_{179} \\
& + 33*z^{220}_{178} + 19*z^{220}_{177} + 7*z^{220}_{176} + 36*z^{220}_{175} \\
& + 30*z^{220}_{174} + 34*z^{220}_{173} + 27*z^{220}_{172} + 3*z^{220}_{171} \\
& + 34*z^{220}_{170} + 5*z^{220}_{169} + 36*z^{220}_{168} + 19*z^{220}_{167} \\
& + 27*z^{220}_{166} + 14*z^{220}_{165} + 10*z^{220}_{164} + 2*z^{220}_{163}
\end{aligned}$$

$$\begin{aligned}
& + 31*z^{220}_{162} + 22*z^{220}_{161} + 7*z^{220}_{160} + 14*z^{220}_{159} \\
& + 5*z^{220}_{158} + 3*z^{220}_{157} + 22*z^{220}_{156} + 32*z^{220}_{155} \\
& + 21*z^{220}_{154} + 17*z^{220}_{153} + 34*z^{220}_{152} + 9*z^{220}_{151} \\
& + 33*z^{220}_{150} + 32*z^{220}_{149} + 24*z^{220}_{148} + 16*z^{220}_{147} \\
& + 19*z^{220}_{146} + 6*z^{220}_{145} + 26*z^{220}_{144} + 24*z^{220}_{143} \\
& + 34*z^{220}_{141} + 25*z^{220}_{140} + 17*z^{220}_{139} + 25*z^{220}_{138} \\
& + 19*z^{220}_{137} + 36*z^{220}_{136} + 7*z^{220}_{134} + 32*z^{220}_{133} \\
& + 24*z^{220}_{132} + 6*z^{220}_{131} + 12*z^{220}_{130} + 30*z^{220}_{129} \\
& + 35*z^{220}_{128} + 13*z^{220}_{127} + 29*z^{220}_{126} + 2*z^{220}_{125} \\
& + 24*z^{220}_{124} + 36*z^{220}_{123} + 34*z^{220}_{122} + 2*z^{220}_{121} \\
& + 33*z^{220}_{120} + 10*z^{220}_{119} + 33*z^{220}_{118} + 2*z^{220}_{117} \\
& + 17*z^{220}_{116} + 33*z^{220}_{115} + 14*z^{220}_{114} + 22*z^{220}_{113} \\
& + 27*z^{220}_{112} + 20*z^{220}_{111} + 23*z^{220}_{110} + 34*z^{220}_{109} \\
& + 6*z^{220}_{108} + 33*z^{220}_{107} + 14*z^{220}_{106} + 28*z^{220}_{105} \\
& + 29*z^{220}_{104} + 36*z^{220}_{103} + 22*z^{220}_{102} + 35*z^{220}_{101} \\
& + 8*z^{220}_{100} + 10*z^{220}_{99} + 10*z^{220}_{98} + 16*z^{220}_{97} \\
& + 19*z^{220}_{96} + 17*z^{220}_{95} + 21*z^{220}_{94} + 13*z^{220}_{93} \\
& + 24*z^{220}_{92} + 36*z^{220}_{91} + 25*z^{220}_{90} + 25*z^{220}_{89} \\
& + 22*z^{220}_{88} + 27*z^{220}_{87} + 28*z^{220}_{86} + 11*z^{220}_{85} \\
& + 3*z^{220}_{84} + 14*z^{220}_{82} + 31*z^{220}_{81} + 7*z^{220}_{80} \\
& + 33*z^{220}_{79} + 33*z^{220}_{78} + 2*z^{220}_{77} + 15*z^{220}_{76} \\
& + 17*z^{220}_{75} + 32*z^{220}_{74} + 4*z^{220}_{73} + 18*z^{220}_{72} \\
& + 10*z^{220}_{71} + 34*z^{220}_{70} + 9*z^{220}_{69} + 3*z^{220}_{68} \\
& + 20*z^{220}_{67} + 33*z^{220}_{66} + 23*z^{220}_{65} + 5*z^{220}_{64} \\
& + 20*z^{220}_{63} + 36*z^{220}_{62} + 29*z^{220}_{61} + 2*z^{220}_{60} \\
& + 25*z^{220}_{59} + 14*z^{220}_{58} + 16*z^{220}_{57} + 31*z^{220}_{56} \\
& + 22*z^{220}_{55} + 31*z^{220}_{54} + 33*z^{220}_{53} + 19*z^{220}_{52} \\
& + 22*z^{220}_{51} + 23*z^{220}_{50} + 36*z^{220}_{49} + 11*z^{220}_{48} \\
& + 15*z^{220}_{47} + 15*z^{220}_{46} + 35*z^{220}_{45} + 7*z^{220}_{44} \\
& + 27*z^{220}_{43} + 28*z^{220}_{42} + 15*z^{220}_{41} + 31*z^{220}_{40} \\
& + 12*z^{220}_{39} + 19*z^{220}_{38} + 21*z^{220}_{37} + 18*z^{220}_{36} \\
& + 3*z^{220}_{35} + 36*z^{220}_{33} + z^{220}_{32} + 35*z^{220}_{31} \\
& + 21*z^{220}_{30} + 2*z^{220}_{29} + 13*z^{220}_{28} + 19*z^{220}_{27} \\
& + 6*z^{220}_{26} + 22*z^{220}_{24} + 26*z^{220}_{23} + 9*z^{220}_{22} \\
& + 7*z^{220}_{21} + 31*z^{220}_{20} + 31*z^{220}_{19} + 9*z^{220}_{18} \\
& + 23*z^{220}_{17} + 23*z^{220}_{16} + 6*z^{220}_{15} + 27*z^{220}_{14} \\
& + 36*z^{220}_{13} + 4*z^{220}_{12} + 26*z^{220}_{11} + 30*z^{220}_{10} \\
& + 9*z^{220}_9 + 8*z^{220}_8 + 15*z^{220}_7 + 26*z^{220}_6 \\
& + 17*z^{220}_5 + 29*z^{220}_4 + 24*z^{220}_3 + 8*z^{220}_2 \\
& + 29*z^{220}_1 : 1)
\end{aligned}$$

Q_3 is given by

$$\begin{aligned}
& (35*z^{220}_{219} + 22*z^{220}_{218} + 36*z^{220}_{216} + 24*z^{220}_{215} \\
& + 19*z^{220}_{214} + 32*z^{220}_{213} + 13*z^{220}_{212} + 19*z^{220}_{211}
\end{aligned}$$

$$\begin{aligned}
& + 3*z^{220}_{210} + 36*z^{220}_{209} + 29*z^{220}_{208} + 35*z^{220}_{206} \\
& + 31*z^{220}_{205} + 32*z^{220}_{204} + 23*z^{220}_{203} + 21*z^{220}_{202} \\
& + 10*z^{220}_{201} + 32*z^{220}_{200} + 32*z^{220}_{199} + 21*z^{220}_{198} \\
& + 16*z^{220}_{197} + 23*z^{220}_{196} + 32*z^{220}_{195} + 12*z^{220}_{194} \\
& + 9*z^{220}_{193} + 35*z^{220}_{192} + 8*z^{220}_{191} + 19*z^{220}_{190} \\
& + 33*z^{220}_{189} + 13*z^{220}_{188} + 11*z^{220}_{187} + 35*z^{220}_{186} \\
& + 25*z^{220}_{185} + 28*z^{220}_{184} + 5*z^{220}_{183} + 7*z^{220}_{182} \\
& + 24*z^{220}_{181} + 35*z^{220}_{180} + 33*z^{220}_{179} + 18*z^{220}_{178} \\
& + 5*z^{220}_{177} + 31*z^{220}_{176} + 18*z^{220}_{175} + 30*z^{220}_{174} \\
& + 27*z^{220}_{173} + 3*z^{220}_{172} + 8*z^{220}_{171} + 24*z^{220}_{170} \\
& + 14*z^{220}_{169} + 2*z^{220}_{168} + 16*z^{220}_{167} + 14*z^{220}_{166} \\
& + 18*z^{220}_{165} + 22*z^{220}_{164} + 32*z^{220}_{163} + 28*z^{220}_{162} \\
& + 7*z^{220}_{161} + 19*z^{220}_{160} + 3*z^{220}_{159} + 14*z^{220}_{158} \\
& + 27*z^{220}_{157} + 35*z^{220}_{156} + 8*z^{220}_{155} + 25*z^{220}_{154} \\
& + 11*z^{220}_{153} + 19*z^{220}_{152} + 21*z^{220}_{151} + 10*z^{220}_{150} \\
& + 2*z^{220}_{149} + 4*z^{220}_{148} + 4*z^{220}_{147} + 31*z^{220}_{146} \\
& + 26*z^{220}_{145} + 17*z^{220}_{143} + 14*z^{220}_{142} + 12*z^{220}_{141} \\
& + 17*z^{220}_{140} + 22*z^{220}_{139} + 30*z^{220}_{138} + 30*z^{220}_{137} \\
& + 15*z^{220}_{136} + 16*z^{220}_{135} + 25*z^{220}_{134} + 8*z^{220}_{133} \\
& + 28*z^{220}_{132} + 5*z^{220}_{131} + 14*z^{220}_{130} + 26*z^{220}_{129} \\
& + 13*z^{220}_{128} + 10*z^{220}_{127} + 13*z^{220}_{126} + 10*z^{220}_{125} \\
& + 17*z^{220}_{124} + 33*z^{220}_{123} + 9*z^{220}_{122} + 9*z^{220}_{121} \\
& + 10*z^{220}_{120} + 12*z^{220}_{119} + 4*z^{220}_{118} + 6*z^{220}_{117} \\
& + 33*z^{220}_{116} + 21*z^{220}_{115} + 14*z^{220}_{114} + 33*z^{220}_{113} \\
& + 11*z^{220}_{112} + 4*z^{220}_{111} + 3*z^{220}_{110} + 3*z^{220}_{109} \\
& + 3*z^{220}_{108} + 3*z^{220}_{107} + 27*z^{220}_{106} + 8*z^{220}_{105} \\
& + 25*z^{220}_{104} + 10*z^{220}_{103} + 24*z^{220}_{102} + 2*z^{220}_{101} \\
& + 12*z^{220}_{100} + 35*z^{220}_{99} + 30*z^{220}_{98} + 14*z^{220}_{97} \\
& + 8*z^{220}_{96} + 16*z^{220}_{95} + 24*z^{220}_{94} + 23*z^{220}_{93} \\
& + 34*z^{220}_{91} + 3*z^{220}_{90} + 13*z^{220}_{89} + 10*z^{220}_{88} \\
& + 20*z^{220}_{87} + 14*z^{220}_{86} + 9*z^{220}_{85} + 36*z^{220}_{84} \\
& + 33*z^{220}_{83} + 12*z^{220}_{82} + 20*z^{220}_{81} + 5*z^{220}_{80} \\
& + 27*z^{220}_{79} + 27*z^{220}_{78} + 9*z^{220}_{77} + 23*z^{220}_{76} \\
& + 4*z^{220}_{75} + 26*z^{220}_{74} + 8*z^{220}_{73} + 11*z^{220}_{72} \\
& + 25*z^{220}_{71} + 35*z^{220}_{70} + 19*z^{220}_{69} + 36*z^{220}_{68} \\
& + 35*z^{220}_{67} + 24*z^{220}_{66} + 8*z^{220}_{65} + 32*z^{220}_{64} \\
& + 10*z^{220}_{63} + 3*z^{220}_{62} + 18*z^{220}_{61} + 35*z^{220}_{60} \\
& + 17*z^{220}_{59} + 30*z^{220}_{58} + 2*z^{220}_{57} + 25*z^{220}_{56} \\
& + 7*z^{220}_{55} + 20*z^{220}_{54} + 27*z^{220}_{53} + z^{220}_{52} \\
& + 10*z^{220}_{51} + 2*z^{220}_{50} + 18*z^{220}_{49} + 30*z^{220}_{48} \\
& + 32*z^{220}_{47} + 20*z^{220}_{46} + 4*z^{220}_{45} + 16*z^{220}_{43} \\
& + 16*z^{220}_{42} + 11*z^{220}_{41} + 8*z^{220}_{40} + 12*z^{220}_{39} \\
& + 15*z^{220}_{38} + 25*z^{220}_{37} + 33*z^{220}_{36} + 4*z^{220}_{35}
\end{aligned}$$

$$\begin{aligned}
& + 11*z^{220^34} + 6*z^{220^33} + 7*z^{220^32} + 32*z^{220^31} \\
& + 19*z^{220^30} + 19*z^{220^29} + 16*z^{220^28} + 10*z^{220^27} \\
& + 7*z^{220^26} + 10*z^{220^25} + 33*z^{220^24} + 25*z^{220^23} \\
& + 21*z^{220^22} + 35*z^{220^21} + 15*z^{220^20} + z^{220^19} \\
& + 19*z^{220^18} + 16*z^{220^17} + 10*z^{220^16} + 18*z^{220^15} \\
& + 17*z^{220^14} + 2*z^{220^13} + 35*z^{220^12} + 30*z^{220^11} \\
& + 17*z^{220^10} + 30*z^{220^9} + 26*z^{220^8} + 9*z^{220^7} \\
& + 34*z^{220^6} + 4*z^{220^5} + 12*z^{220^4} + 16*z^{220^3} \\
& + 27*z^{220^2} + 12*z^{220} + 36 \\
& : 21*z^{220^219} + 24*z^{220^218} \\
& + 33*z^{220^217} + 31*z^{220^216} + 29*z^{220^215} + 16*z^{220^214} \\
& + 26*z^{220^213} + 7*z^{220^212} + 15*z^{220^211} + 9*z^{220^210} \\
& + 19*z^{220^209} + 18*z^{220^208} + 16*z^{220^207} + 23*z^{220^206} \\
& + 27*z^{220^205} + 16*z^{220^204} + 5*z^{220^203} + 10*z^{220^202} \\
& + 2*z^{220^201} + 19*z^{220^200} + 19*z^{220^199} + 8*z^{220^198} \\
& + 30*z^{220^197} + 9*z^{220^196} + 27*z^{220^195} + 7*z^{220^194} \\
& + 20*z^{220^193} + 8*z^{220^192} + 29*z^{220^191} + 10*z^{220^190} \\
& + 32*z^{220^189} + 9*z^{220^188} + 4*z^{220^187} + 31*z^{220^186} \\
& + 8*z^{220^185} + 4*z^{220^184} + 8*z^{220^183} + 11*z^{220^182} \\
& + 13*z^{220^181} + 5*z^{220^180} + 29*z^{220^179} + 13*z^{220^178} \\
& + 20*z^{220^177} + 9*z^{220^176} + 3*z^{220^175} + 32*z^{220^174} \\
& + 3*z^{220^173} + 25*z^{220^172} + 33*z^{220^171} + 36*z^{220^170} \\
& + 11*z^{220^169} + 22*z^{220^168} + 18*z^{220^167} + 7*z^{220^166} \\
& + 4*z^{220^165} + 9*z^{220^164} + 33*z^{220^163} + 33*z^{220^162} \\
& + 18*z^{220^161} + 3*z^{220^160} + 35*z^{220^159} + 31*z^{220^158} \\
& + 20*z^{220^157} + 28*z^{220^155} + 33*z^{220^154} + 30*z^{220^153} \\
& + 28*z^{220^152} + 18*z^{220^151} + z^{220^150} + 34*z^{220^149} \\
& + 16*z^{220^148} + 23*z^{220^147} + 30*z^{220^146} + 3*z^{220^144} \\
& + 28*z^{220^143} + 8*z^{220^142} + 35*z^{220^140} + 11*z^{220^139} \\
& + 16*z^{220^138} + 20*z^{220^137} + 31*z^{220^136} + 11*z^{220^135} \\
& + 24*z^{220^134} + 29*z^{220^133} + 29*z^{220^132} + 8*z^{220^131} \\
& + 25*z^{220^130} + 11*z^{220^129} + 35*z^{220^128} + 36*z^{220^127} \\
& + 33*z^{220^126} + 18*z^{220^125} + 8*z^{220^124} + 9*z^{220^123} \\
& + 31*z^{220^122} + 29*z^{220^121} + 7*z^{220^120} + 4*z^{220^119} \\
& + 3*z^{220^118} + 13*z^{220^117} + 35*z^{220^116} + 17*z^{220^115} \\
& + 6*z^{220^114} + 3*z^{220^113} + 13*z^{220^112} + 5*z^{220^111} \\
& + 31*z^{220^110} + 32*z^{220^109} + 17*z^{220^108} + 28*z^{220^107} \\
& + 21*z^{220^106} + 14*z^{220^105} + 25*z^{220^104} + 17*z^{220^103} \\
& + 33*z^{220^102} + 19*z^{220^101} + 4*z^{220^100} + 2*z^{220^99} \\
& + 7*z^{220^98} + 34*z^{220^97} + 15*z^{220^96} + 7*z^{220^95} \\
& + 34*z^{220^94} + 22*z^{220^93} + 22*z^{220^92} + 11*z^{220^91} \\
& + 33*z^{220^90} + 32*z^{220^89} + 19*z^{220^88} + 21*z^{220^87}
\end{aligned}$$

$$\begin{aligned}
& + 23*z^{220^86} + 34*z^{220^85} + 35*z^{220^84} + 23*z^{220^83} \\
& + 27*z^{220^82} + 25*z^{220^81} + 26*z^{220^80} + 2*z^{220^79} \\
& + 33*z^{220^78} + 32*z^{220^77} + 8*z^{220^76} + 32*z^{220^75} \\
& + 15*z^{220^74} + 17*z^{220^73} + 31*z^{220^72} + 7*z^{220^71} \\
& + 8*z^{220^70} + 8*z^{220^69} + 22*z^{220^68} + 7*z^{220^67} \\
& + 14*z^{220^66} + 15*z^{220^65} + 26*z^{220^64} + 26*z^{220^63} \\
& + 35*z^{220^62} + 19*z^{220^61} + 18*z^{220^60} + 22*z^{220^59} \\
& + 25*z^{220^57} + 4*z^{220^56} + 5*z^{220^55} + 4*z^{220^54} \\
& + 20*z^{220^53} + 32*z^{220^52} + 17*z^{220^51} + 14*z^{220^50} \\
& + 31*z^{220^49} + 9*z^{220^48} + 30*z^{220^47} + 20*z^{220^46} \\
& + 7*z^{220^45} + 16*z^{220^43} + 23*z^{220^42} + 12*z^{220^41} \\
& + 21*z^{220^40} + 14*z^{220^39} + 8*z^{220^38} + 14*z^{220^37} \\
& + 35*z^{220^36} + 14*z^{220^35} + 22*z^{220^34} + 8*z^{220^33} \\
& + z^{220^32} + 24*z^{220^31} + 21*z^{220^30} + 33*z^{220^29} \\
& + 21*z^{220^28} + 22*z^{220^26} + 33*z^{220^25} + 13*z^{220^24} \\
& + 13*z^{220^23} + 5*z^{220^22} + 35*z^{220^21} + 3*z^{220^20} \\
& + 31*z^{220^19} + 13*z^{220^18} + 33*z^{220^17} + 30*z^{220^16} \\
& + 16*z^{220^15} + 30*z^{220^14} + 16*z^{220^13} + 11*z^{220^12} \\
& + 35*z^{220^11} + 22*z^{220^10} + 11*z^{220^9} + 8*z^{220^8} \\
& + z^{220^7} + 25*z^{220^6} + 8*z^{220^5} + 27*z^{220^4} + z^{220^3} \\
& + 29*z^{220^2} + 34*z^{220} + 29 : 1)
\end{aligned}$$