樂器設計比賽 Musical Instrument Design Competition

http://i.cs.hku.hk/~music/

Sound, Music and Engineering
聲、樂及工程

Dr. YIP Chi Lap [Beta]
Faculty of Engineering, HKU
香港大學工程學院 葉志立博士

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Science is about why,
Engineering is about how.

科學問為何
工程問如何

A bit of revision first.....

先溫書……

Quick Quiz!
問答！

- Let wavelength of sound be λ, sound speed in air v and sound frequency f. Point out which statement is correct on each column of the table.
  設聲波波長為 λ、聲音傳播速度 v 、聲音頻率 f。指出下表中每列正確之句子。

	Formula 算式	Sound speed 聲速	Sound frequency 聲頻
A	$f = v / \lambda$	$v \approx 340\ ms^{-1}$	$f \leq 20Hz$
B	$v = f / \lambda$	$v \approx 1494\ ms^{-1}$	$20Hz \leq f \leq 20kHz$
C	$\lambda = f / v$	$v \approx 3 \times 10^{8}\ ms^{-1}$	$20kHz \leq f$

Have you done your homework?
有沒有做功課？

Calculate the frequencies!
計頻率！

✦ Can you find out the frequencies of the top notes?
你能計出頂音的頻率嗎？

Interval 音程	Frequency ratio 頻率比	Bottom note 底音	Top note 頂音
Major second 大二度	9:8	220 Hz	
Minor second 小二度	16:15	220 Hz	
Augmented fourth 增四度	45:32	220 Hz	
Diminished fifth 減五度	64:45	220 Hz	
Major seventh 大七度	15:8	220 Hz	
Minor seventh 小七度	16:9	220 Hz	

Frequency table
頻率表

	Interval 音程	Frequency ratio 頻率比	Bottom note 底音	Top note 頂音
Perfect consonant interval 完全協和音程	Unison 純一度	1:1	220 Hz	220 Hz
	Octave 全八度	2:1	220 Hz	440 Hz
	Perfect fifth 全五度	3:2	220 Hz	330 Hz
	Perfect fourth 全四度	4:3	220 Hz	293.$\dot{3}$ Hz
Imperfect consonant interval 不完全協和音程	Major third 大三度	5:4	220 Hz	275 Hz
	Minor third 小三度	6:5	220 Hz	264 Hz
	Major sixth 大六度	5:3	220 Hz	366.$\dot{6}$ Hz
	Minor sixth 小六度	8:5	220 Hz	352 Hz
Dissonant interval 不協和音程	Major second 大二度	9:8	220 Hz	247.5 Hz
	Minor second 小二度	16:15	220 Hz	234.$\dot{6}$ Hz
	Augmented fourth 增四度	45:32	220 Hz	309.375 Hz
	Diminished fifth 減五度	64:45	220 Hz	312.$\dot{8}$ Hz
	Major seventh 大七度	15:8	220 Hz	412.5 Hz
	Minor seventh 小七度	16:9	220 Hz	391.$\dot{1}$ Hz

Frequency table
頻率表

	Interval 音程	Frequency ratio 頻率比	Bottom note 底音	Top note 頂音
P	Unison 純一度	1:1	220 Hz	220 Hz
D	Minor second 小二度	16:15	220 Hz	234.$\dot{6}$ Hz
D	Major second 大二度	9:8	220 Hz	247.5 Hz
I	Minor third 小三度	6:5	220 Hz	264 Hz
I	Major third 大三度	5:4	220 Hz	275 Hz
P	Perfect fourth 全四度	4:3	220 Hz	293.$\dot{3}$ Hz
D	Augmented fourth 增四度	45:32	220 Hz	309.375 Hz
D	Diminished fifth 減五度	64:45	220 Hz	312.$\dot{8}$ Hz
P	Perfect fifth 全五度	3:2	220 Hz	330 Hz
I	Minor sixth 小六度	8:5	220 Hz	352 Hz
I	Major sixth 大六度	5:3	220 Hz	366.$\dot{6}$ Hz
D	Minor seventh 小七度	16:9	220 Hz	391.$\dot{1}$ Hz
D	Major seventh 大七度	15:8	220 Hz	412.5 Hz
P	Octave 全八度	2:1	220 Hz	440 Hz

Tuning systems
律式

- Just intonation 純律
  - Frequency ratios are simple whole number ratios
    頻率比為簡單比例
- Pythagorean tuning 畢達哥拉斯律式
  - Frequency ratios are based on perfect fifth 3:2 and perfect octave 2:1
    頻率比建基於大五度的3:2及全八度的2:1
- Equal temperament tuning 十二平均律
  - Frequency ratio of notes the same interval apart is the same.
    音程一樣的任何兩音的頻率比一樣。

Simple ratios used in just intonation tuning
純律用的簡單頻率比例

	Interval 音程	Frequency ratio 頻率比	Bottom note 底音	Top note 頂音
P	Unison 純一度	1:1	220 Hz	220 Hz
D	Minor second 小二度	16:15	220 Hz	234.$\dot{6}$ Hz
D	Major second 大二度	9:8	220 Hz	247.5 Hz
I	Minor third 小三度	6:5	220 Hz	264 Hz
I	Major third 大三度	5:4	220 Hz	275 Hz
P	Perfect fourth 全四度	4:3	220 Hz	293.$\dot{3}$ Hz
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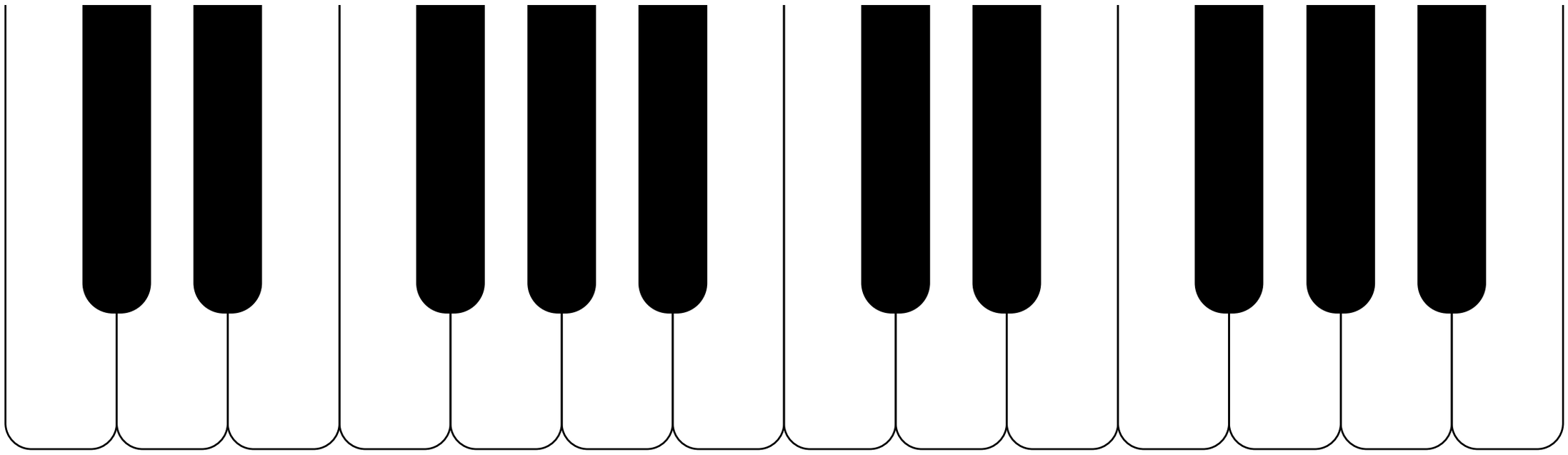
D	Major seventh 大七度	15:8	220 Hz	412.5 Hz
P	Octave 全八度	2:1	220 Hz	440 Hz

Simple ratios used in just intonation tuning
純律用的簡單頻率比例

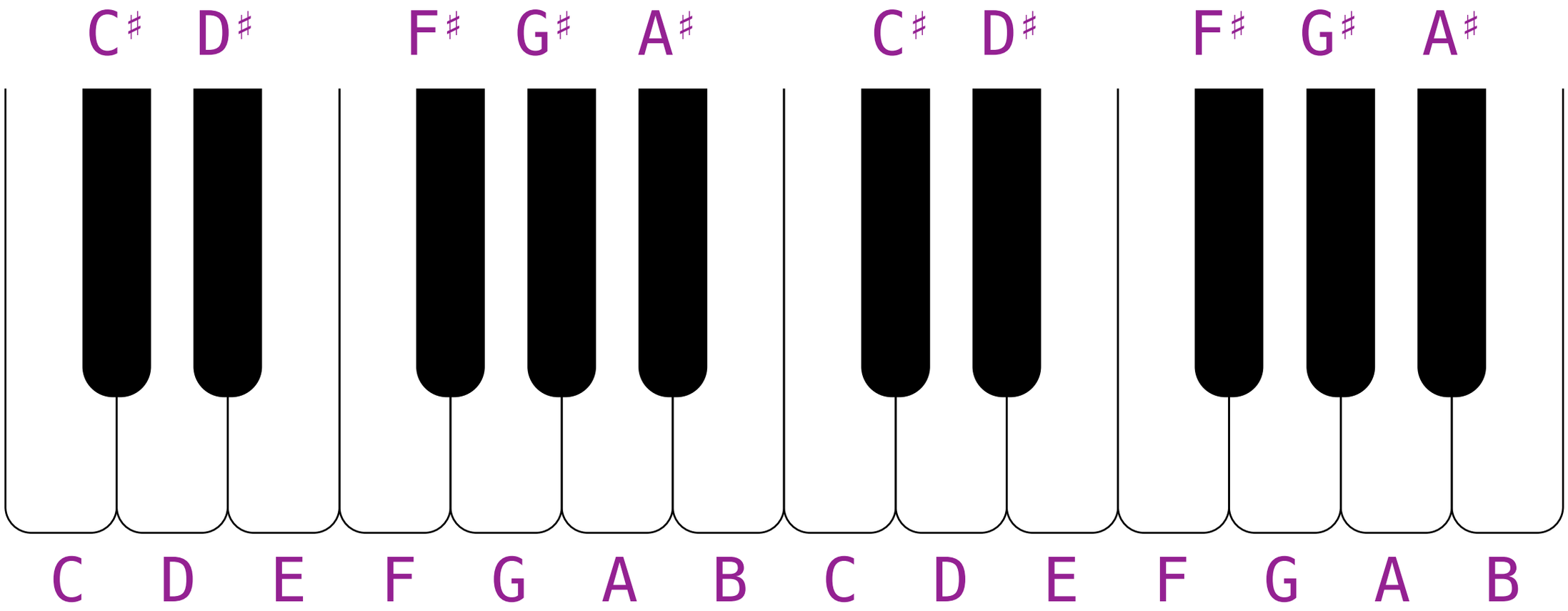
	Interval 音程	Frequency ratio 頻率比	
P	Unison 純一度	1:1	1
D	Minor second 小二度	16:15	$1.0\dot{6}$
D	Major second 大二度	9:8	1.125
I	Minor third 小三度	6:5	1.2
I	Major third 大三度	5:4	1.25
P	Perfect fourth 全四度	4:3	$1.\dot{3}$
D	Augmented fourth 增四度	45:32	1.40625
D	Diminished fifth 減五度	64:45	$1.4\dot{2}$
P	Perfect fifth 全五度	3:2	1.5
I	Minor sixth 小六度	8:5	1.6
I	Major sixth 大六度	5:3	$1.\dot{6}$
D	Minor seventh 小七度	16:9	$1.\dot{7}$
D	Major seventh 大七度	15:8	1.875
P	Octave 全八度	2:1	2

The trouble of naming notes
給音名的煩惱

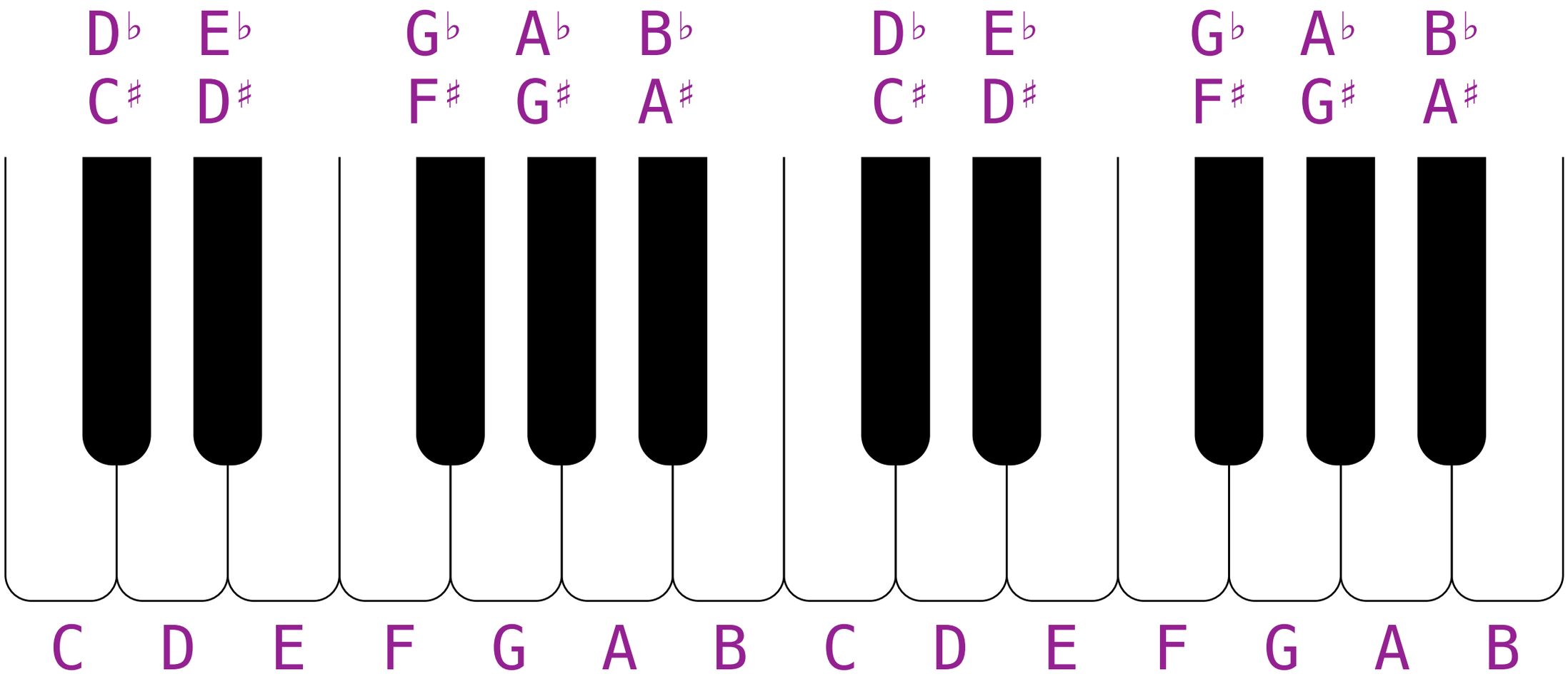
✦ Name the notes 給音名



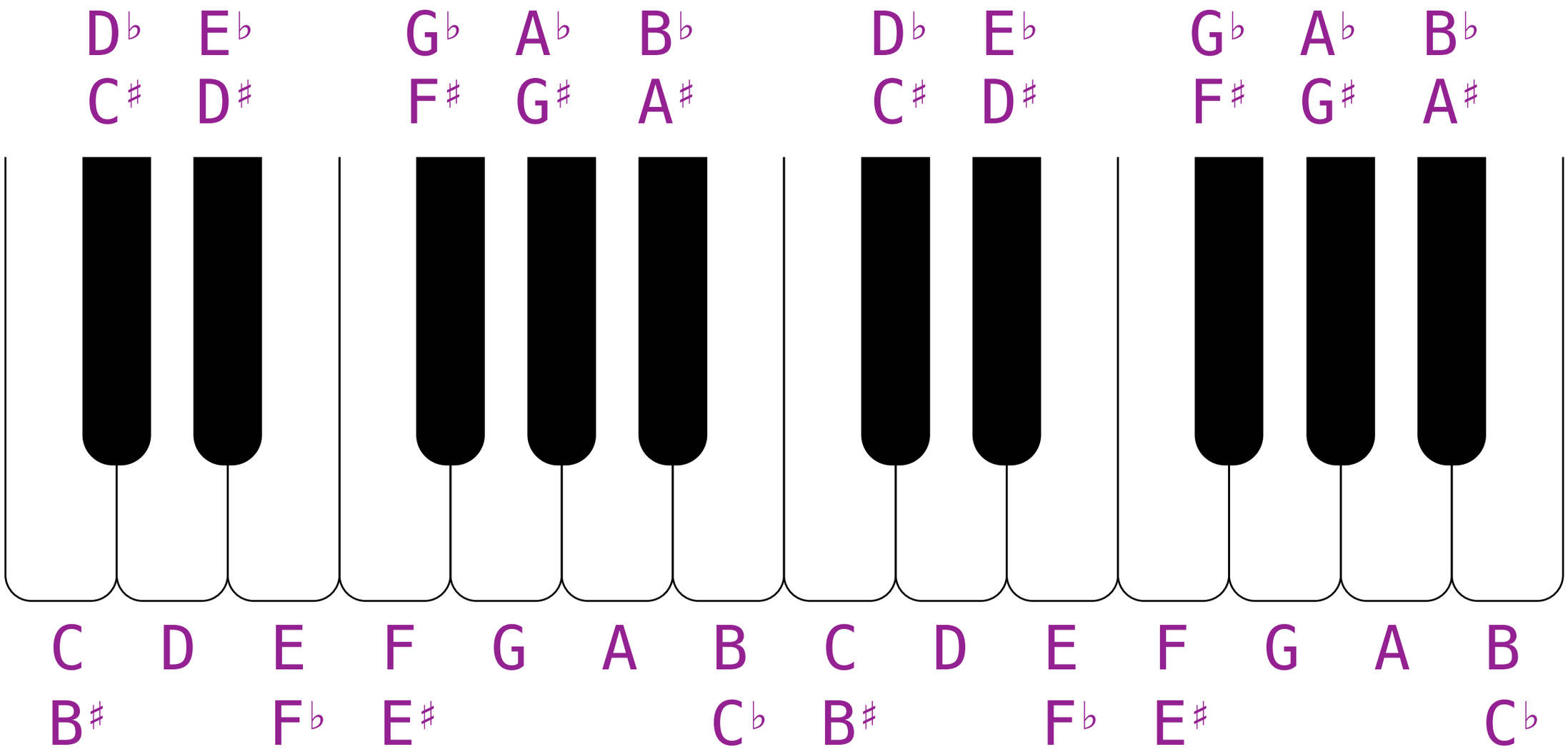
The trouble of naming notes
給音名的煩惱



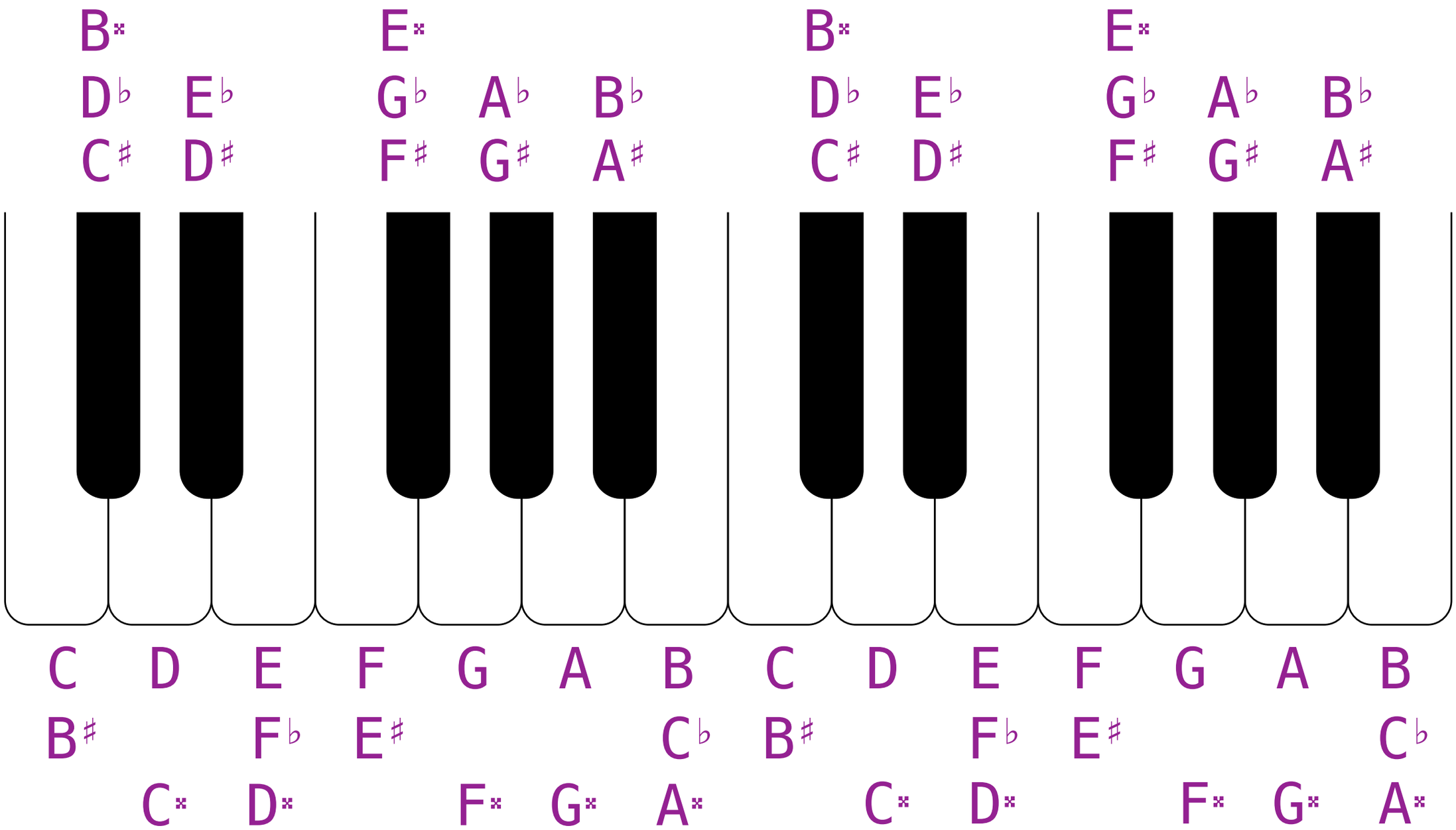
The trouble of naming notes
給音名的煩惱



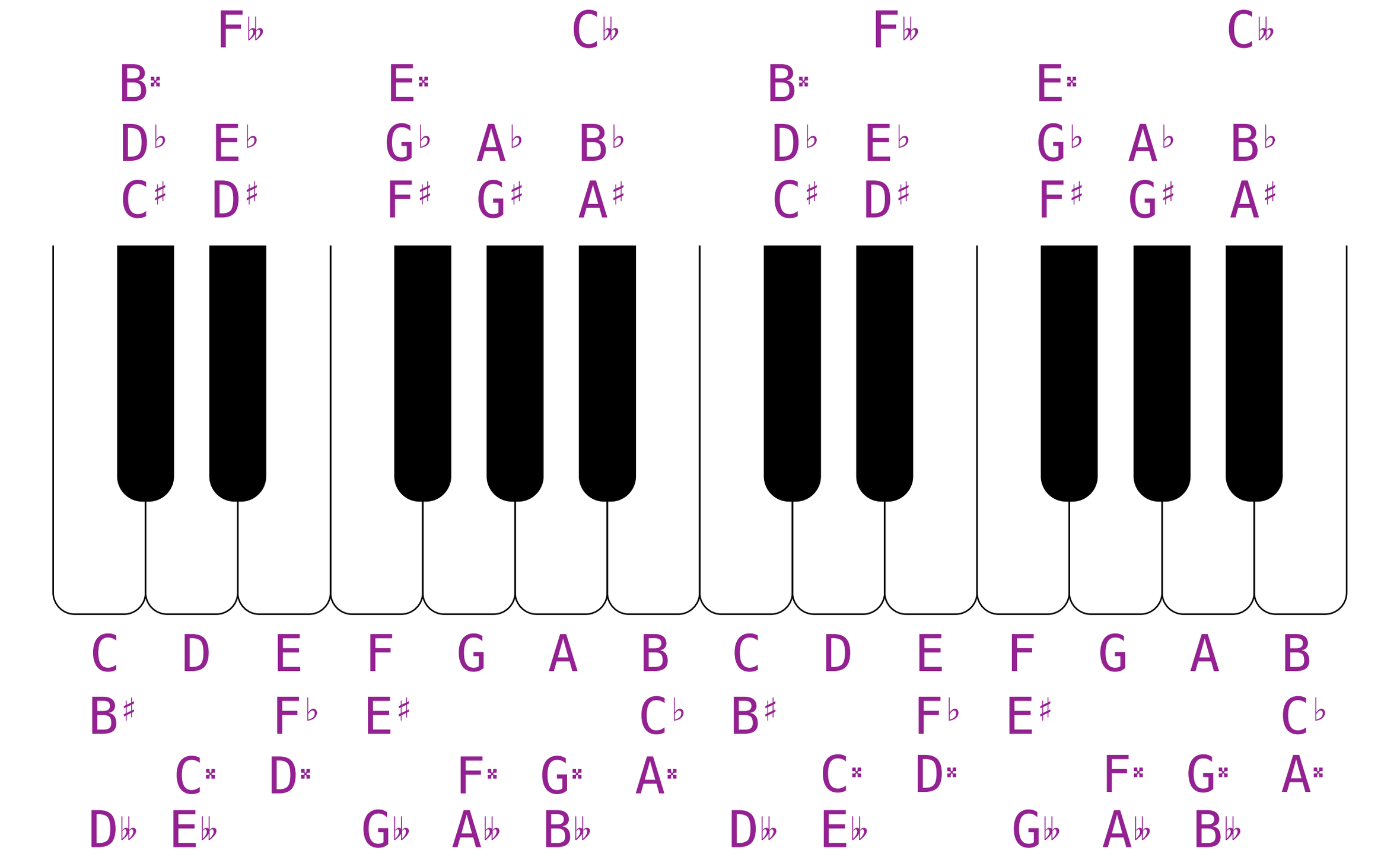
The trouble of naming notes
給音名的煩惱



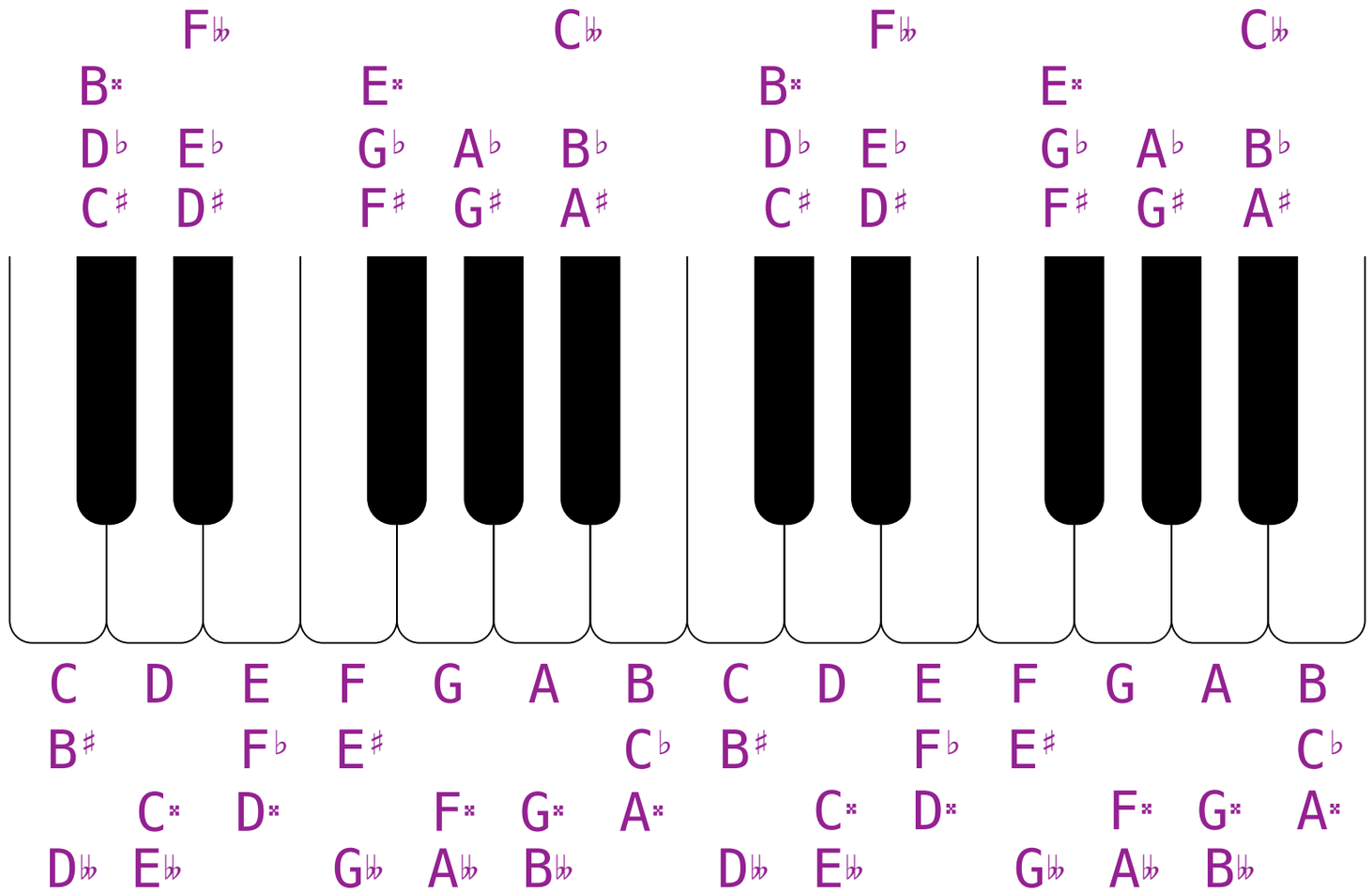
The trouble of naming notes
給音名的煩惱



The trouble of naming notes
給音名的煩惱



Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈



C → G → D → A → E → B → F♯ → C♯ → G♯ → D♯ → A♯ → E♯ → C

C ← A𝄫 ← E𝄫 ← B𝄫 ← F♭ ← C♭ ← G♭ ← D♭ ← A♭ ← E♭ ← B♭ ← F ← C

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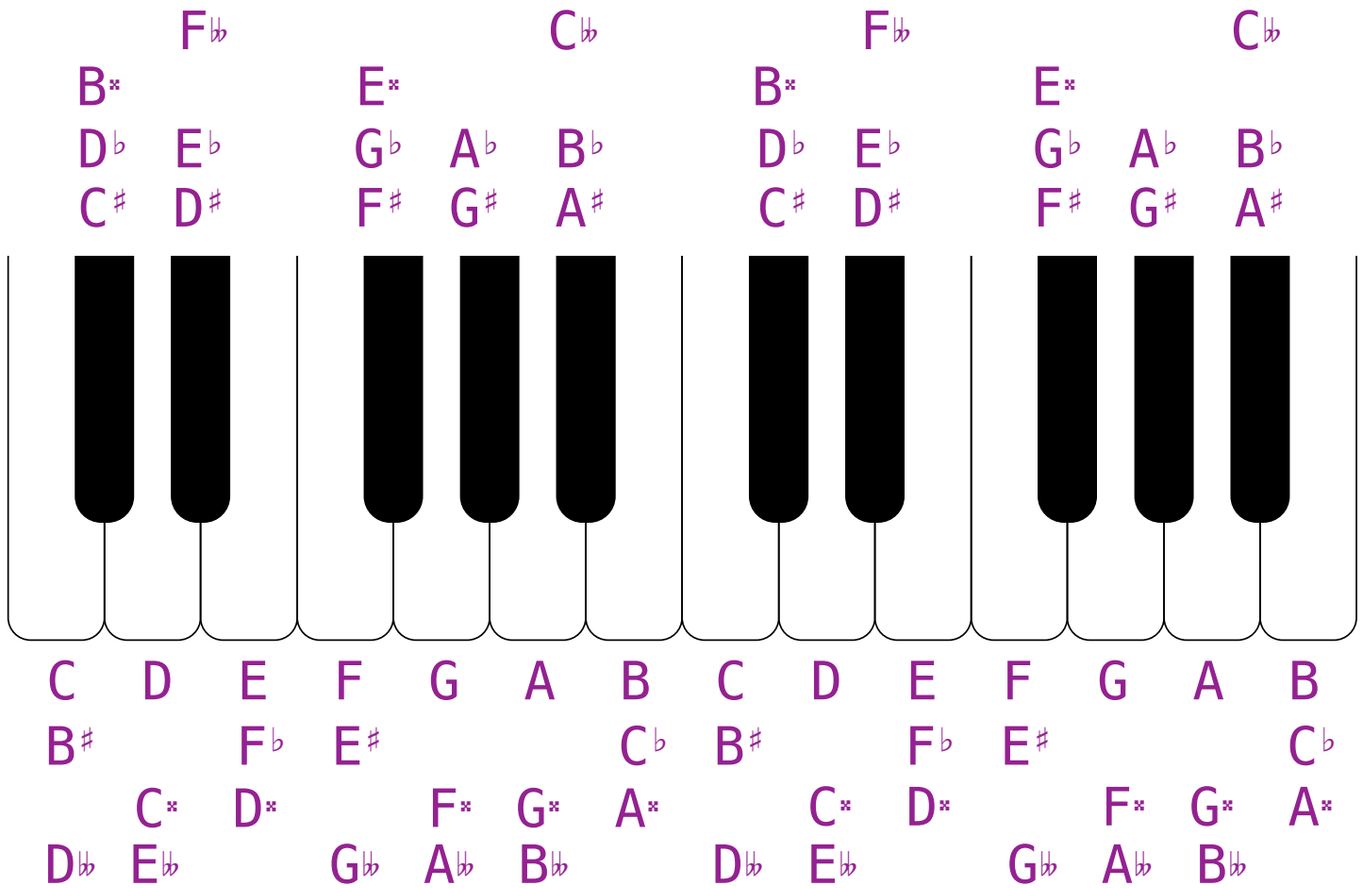
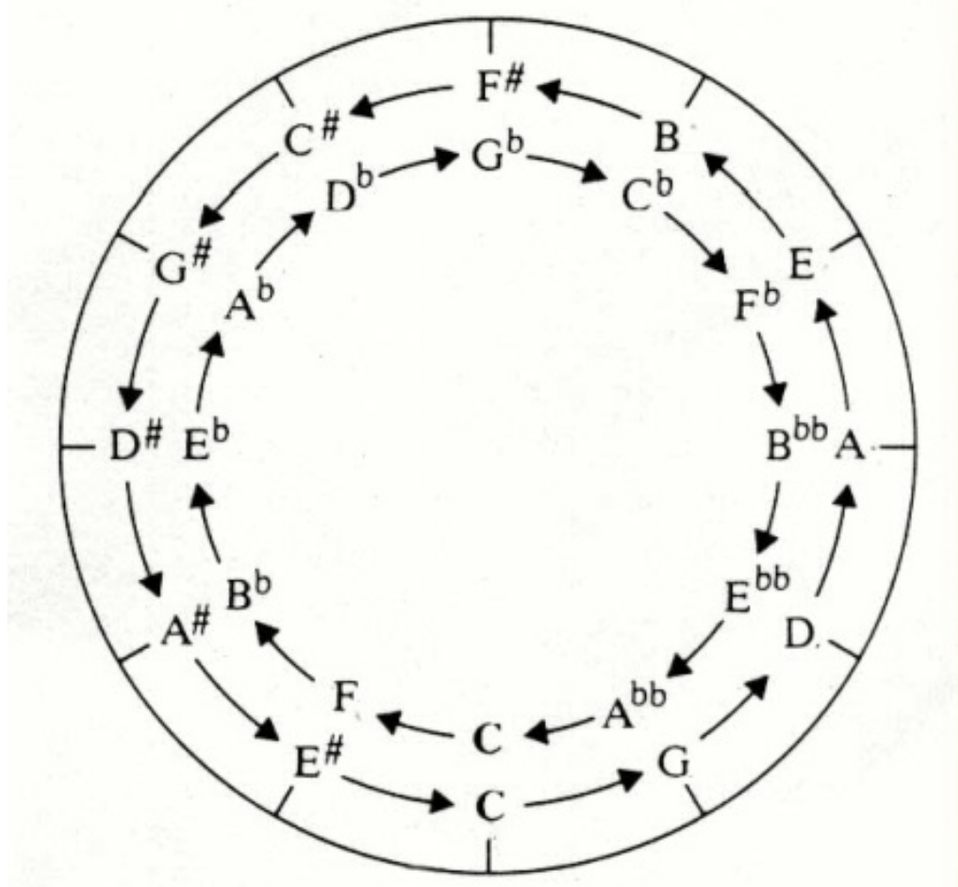
畢達哥拉斯律式（五度相生律）建基於五度圈



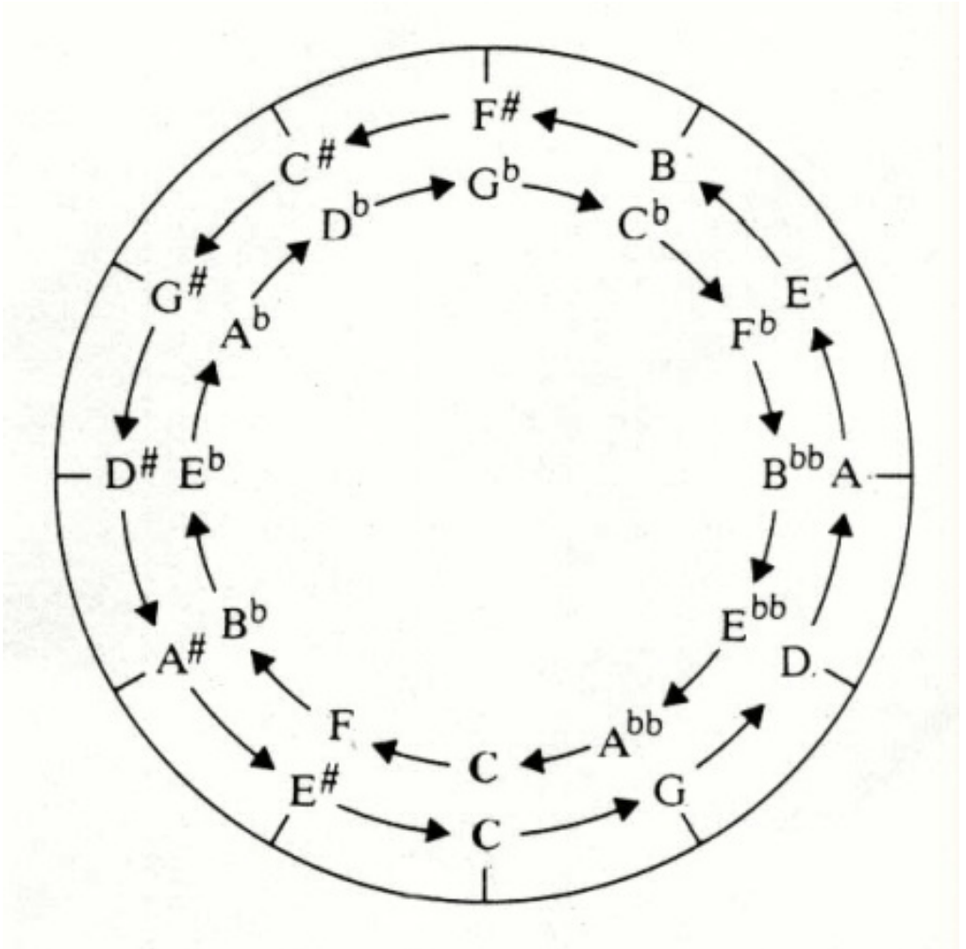


C⟶G⟶D⟶A⟶E⟶B⟶F♯⟶C♯⟶G♯⟶D♯⟶A♯⟶E♯⟶C

C⟵A♭♭⟵E♭♭⟵B♭♭⟵F♭⟵C♭⟵G♭⟵D♭⟵A♭⟵E♭⟵B♭⟵F⟵C

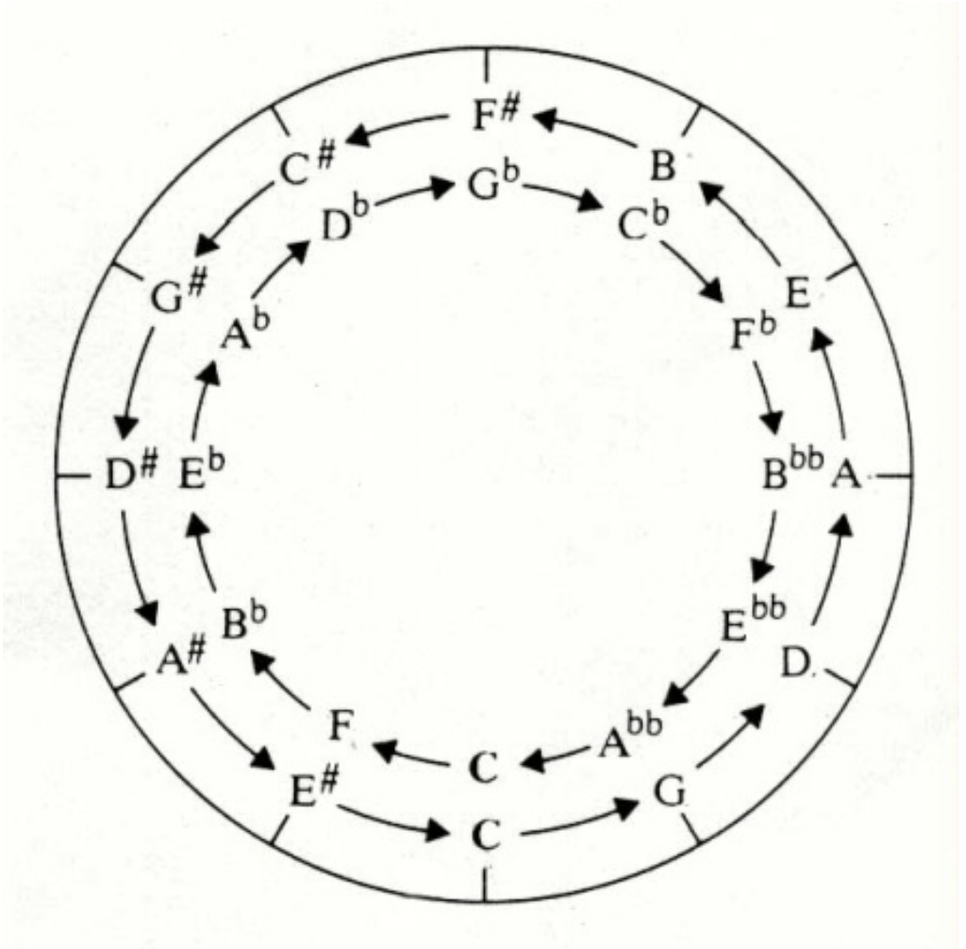
Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈

Note 音	Frequency ratio 頻率比	
G♭		
D♭		
A♭		
E♭		
B♭		
F		
C	1:1	1
G		
D		
A		
E		
B		
F♯		



Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈

Note 音	Frequency ratio 頻率比	
G♭		
D♭		
A♭		
E♭		
B♭		
F	4:3	$1.\dot{3}$
C	1:1	1
G	3:2	1.5
D		
A		
E		
B		
F♯		



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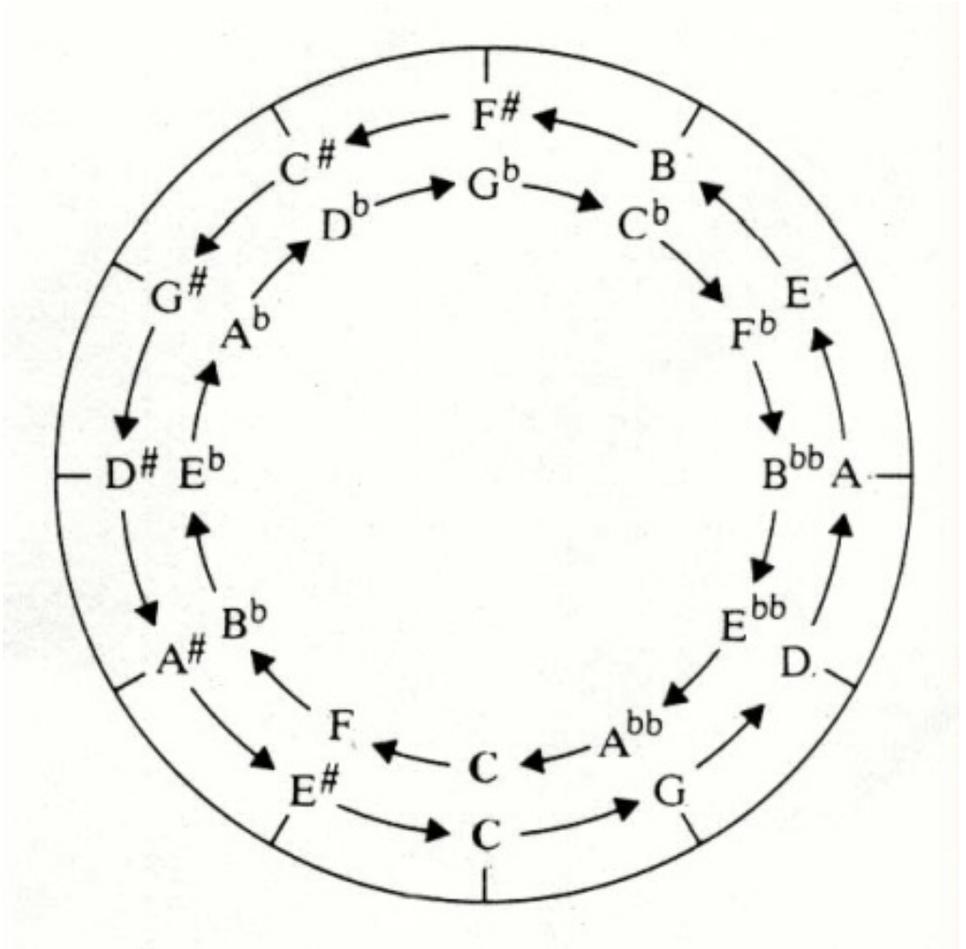
畢達哥拉斯律式（五度相生律）建基於五度圈

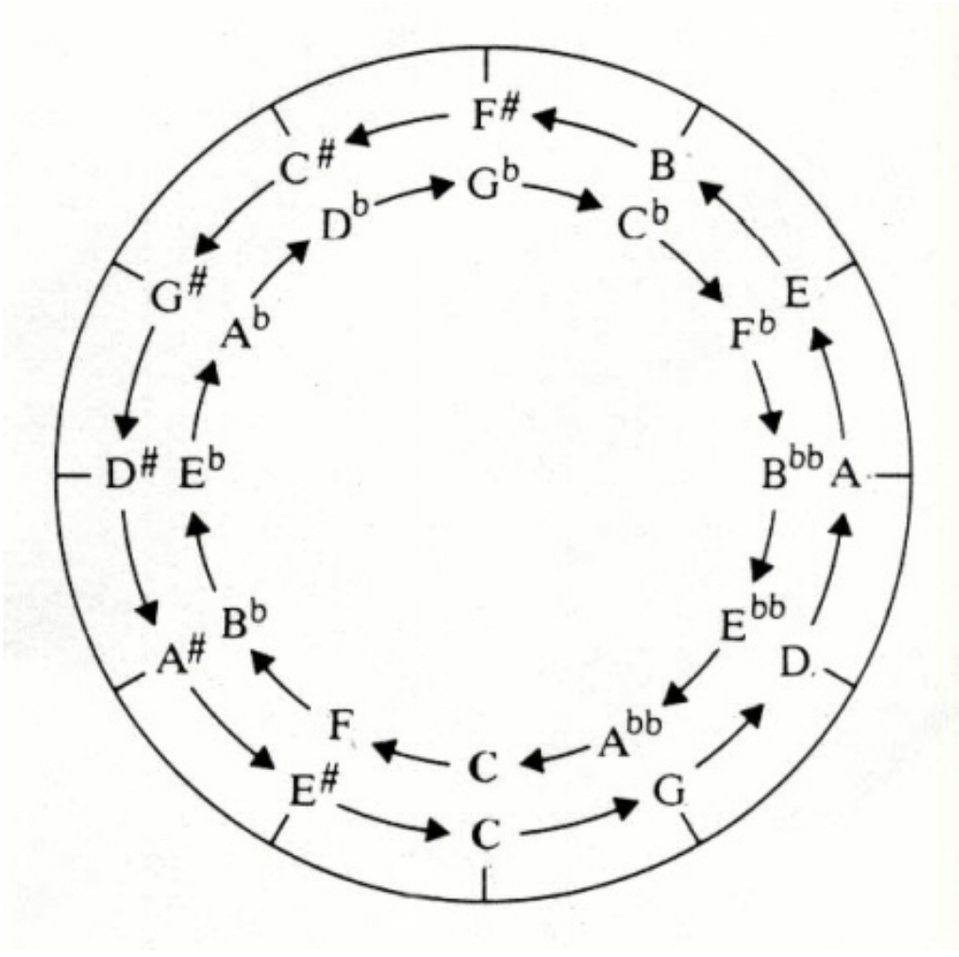
Note 音	Frequency ratio 頻率比	
G♭		
D♭		
A♭		
E♭		
B♭	16:9	$1.7\dot{}$
F	4:3	$1.3\dot{}$
C	1:1	1
G	3:2	1.5
D	9:8	1.125
A		
E		
B		
F♯		



Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈

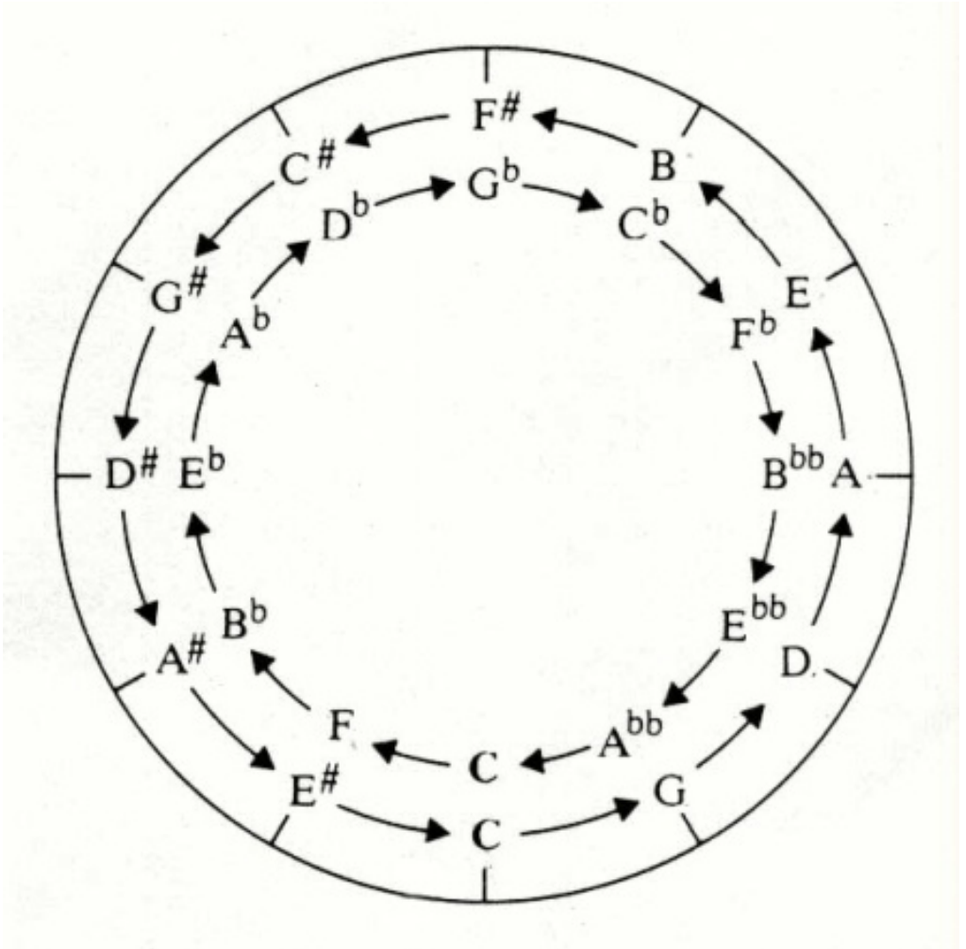
Note 音	Frequency ratio 頻率比	
G♭		
D♭		
A♭		
E♭	32:27	1.1̇85̇
B♭	16:9	1.7̇
F	4:3	1.3̇
C	1:1	1
G	3:2	1.5
D	9:8	1.125
A	27:16	1.6875
E		
B		
F♯		

Which key is this?
這是甚麼調？



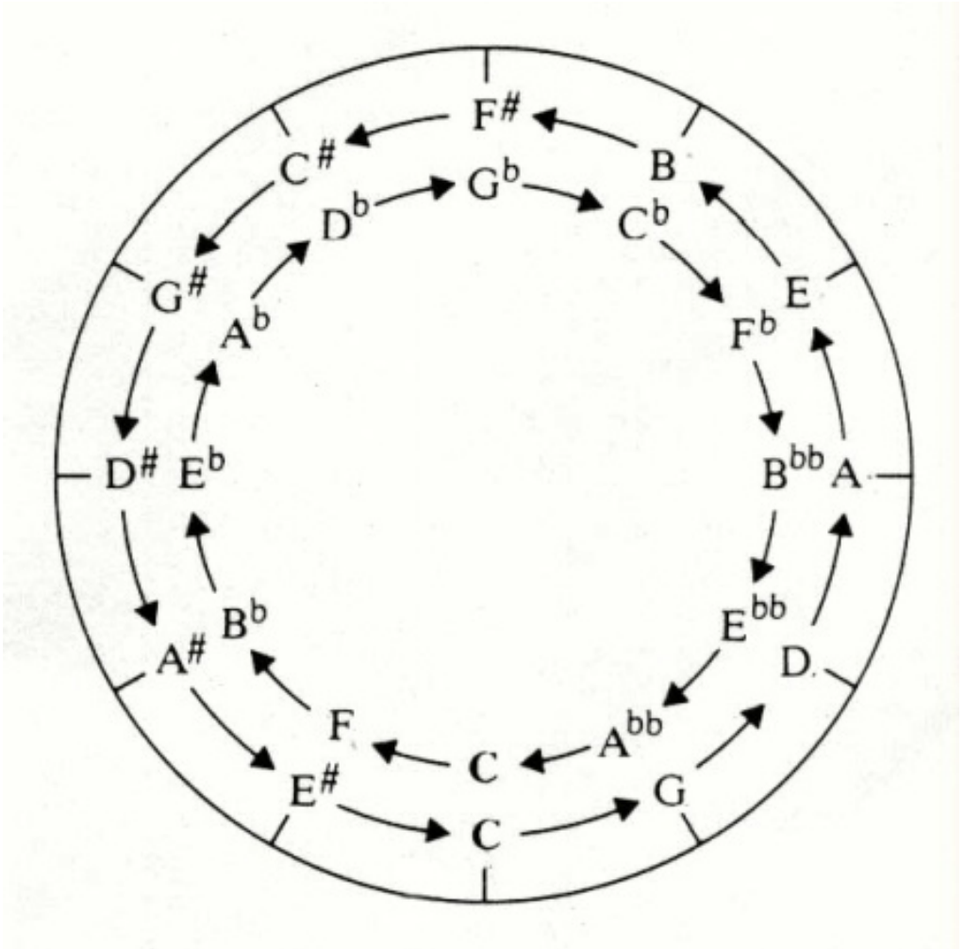
Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈

Note 音	Frequency ratio 頻率比	
G♭		
D♭		
A♭	128:81	$1.\dot{5}80246913\dot{3}$
E♭	32:27	$1.\dot{1}8\dot{5}$
B♭	16:9	$1.\dot{7}$
F	4:3	$1.\dot{3}$
C	1:1	1
G	3:2	1.5
D	9:8	1.125
A	27:16	1.6875
E	81:64	1.265625
B		
F♯		



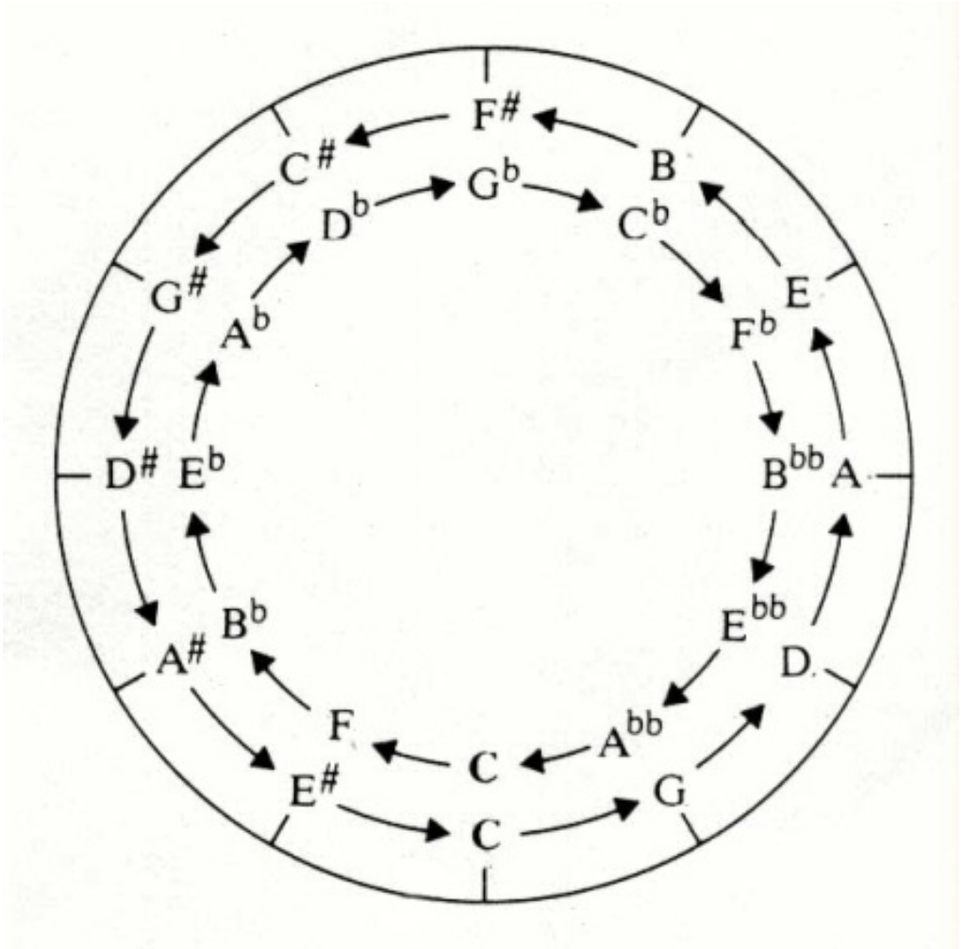
Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈

Note 音	Frequency ratio 頻率比	
G♭		
D♭	256:243	1.0̇5349794238
A♭	128:81	1.5̇80246913̇
E♭	32:27	1.1̇85̇
B♭	16:9	1.7̇
F	4:3	1.3̇
C	1:1	1
G	3:2	1.5
D	9:8	1.125
A	27:16	1.6875
E	81:64	1.265625
B	243:128	1.8984375
F♯		



Pythagorean tuning is based on the Circle of Fifths
畢達哥拉斯律式（五度相生律）建基於五度圈

Note 音	Frequency ratio 頻率比	
G♭	1024:729	1.40466392318
D♭	256:243	1.05349794238
A♭	128:81	$1.\dot{5}80246913\dot{3}$
E♭	32:27	$1.\dot{1}85\dot{2}$
B♭	16:9	$1.\dot{7}$
F	4:3	$1.\dot{3}$
C	1:1	1
G	3:2	1.5
D	9:8	1.125
A	27:16	1.6875
E	81:64	1.265625
B	243:128	1.8984375
F♯	729:512	1.423828125



Pythagorean tuning is based on the Circle of Fifths
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G♭	1024:729	1.40466392318
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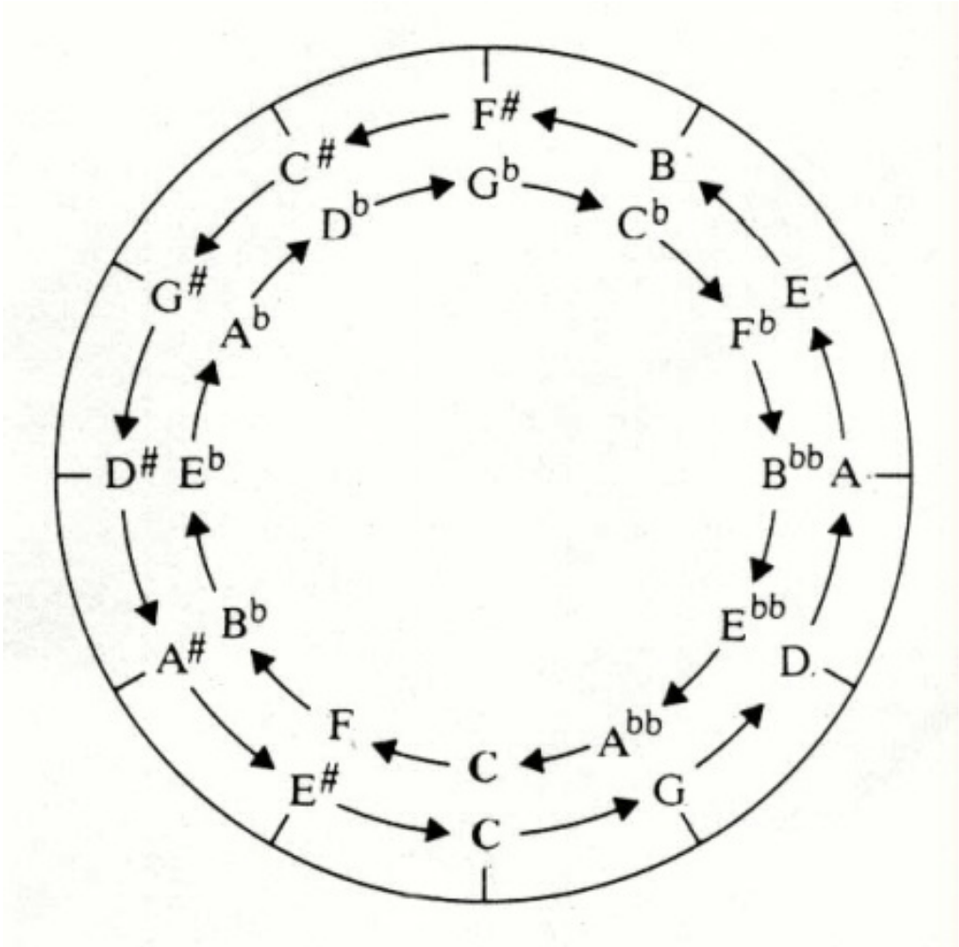
E♭	32:27	1.1̇85̇
B♭	16:9	1.7̇
F	4:3	1.3̇
C	1:1	1
G	3:2	1.5
D	9:8	1.125
A	27:16	1.6875
E	81:64	1.265625
B	243:128	1.8984375
F♯	729:512	1.423828125

1024/729 ≠ 729/512

G♭ ≠ F♯



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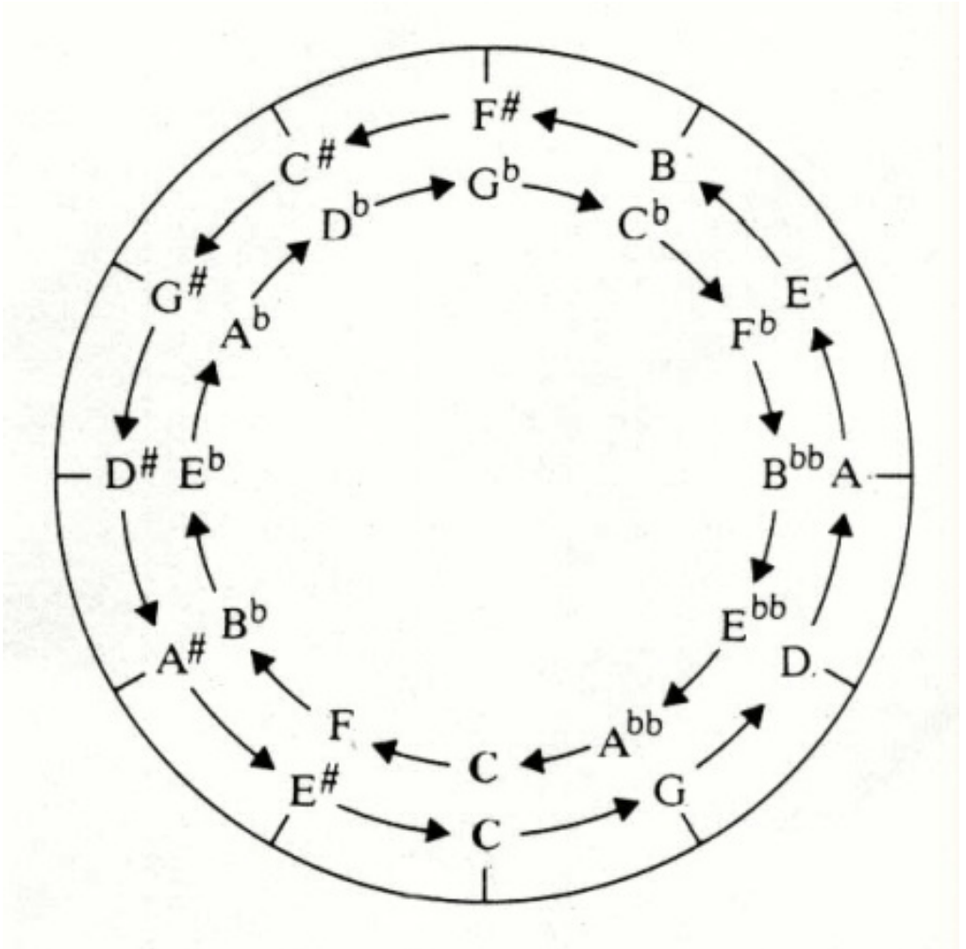
畢達哥拉斯律式（五度相生律）建基於五度圈

Note 音	Frequency ratio 頻率比	
C	1:1	1
D♭	256:243	1.05349794238
D	9:8	1.125
E♭	32:27	$1.\dot{1}8\dot{5}$
E	81:64	1.265625
F	4:3	$1.\dot{3}$
G♭	1024:729	1.40466392318
F♯	729:512	1.423828125
G	3:2	1.5
A♭	128:81	$1.\dot{5}80246913\dot{3}$
A	27:16	1.6875
B♭	16:9	$1.\dot{7}$
B	243:128	1.8984375

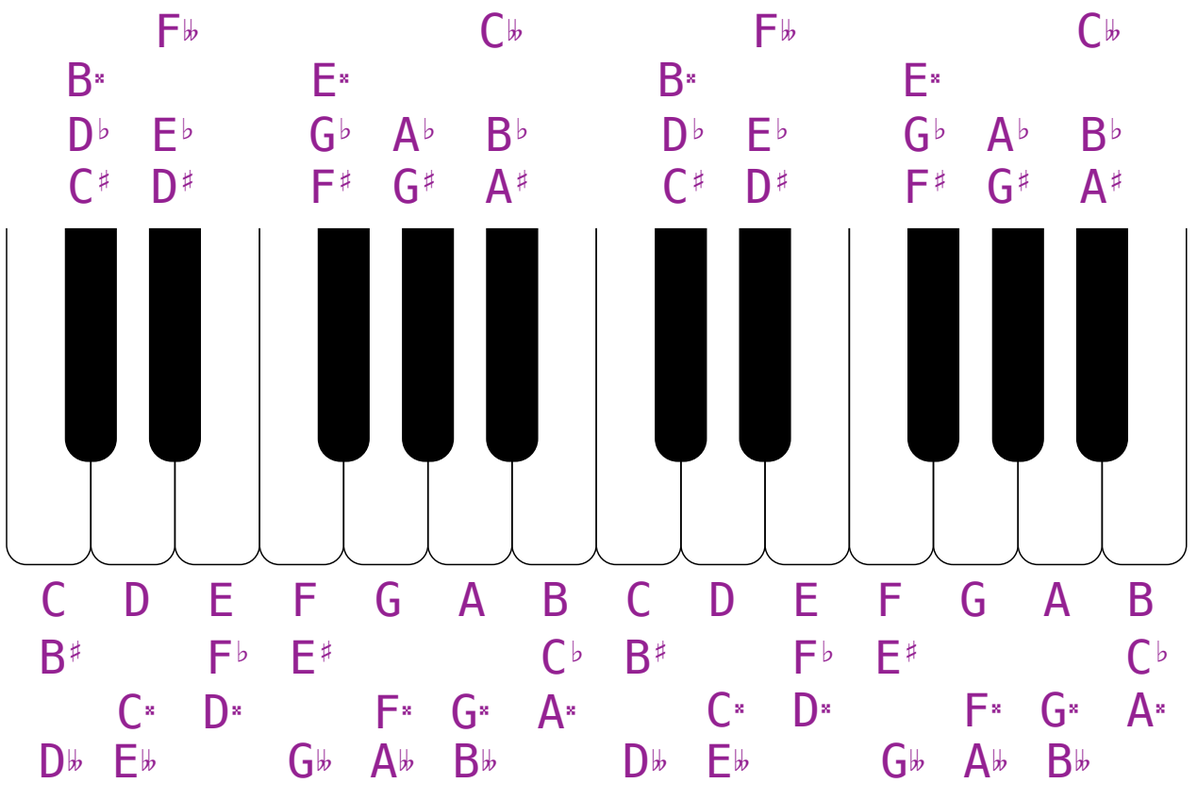


Equal temperament tuning
十二平均律

- ✦ Up an octave 高八度： $f \rightarrow 2f$
- ✦ Frequency ratio of notes the same interval apart is the same.
  音程一樣的任何兩音的頻率比一樣。
- ✦ There are 12 semitones in an octave.
  一個八度有12個半音。
- ✦ 半音頻率比為 $2^{1/12} \approx 1.059463094359295 3$

Equal temperament tuning
十二平均律

Note 音	Frequency ratio 頻率比	
C	$2^{0/12}$	1
C♯=D♭	$2^{1/12}$	1.05946309435
D	$2^{2/12}$	1.12246204830
D♯=E♭	$2^{3/12}$	1.18920711500
E	$2^{4/12}$	1.25992104989
F	$2^{5/12}$	1.33483985417
F♯=G♭	$2^{6/12}$	1.41421356237
G	$2^{7/12}$	1.49830707687
G♯=A♭	$2^{8/12}$	1.58740105196
A	$2^{9/12}$	1.68179283050
A♯=B♭	$2^{10/12}$	1.78179743628
B	$2^{11/12}$	1.88774862536



Let's compare!
讓我們比較一下！

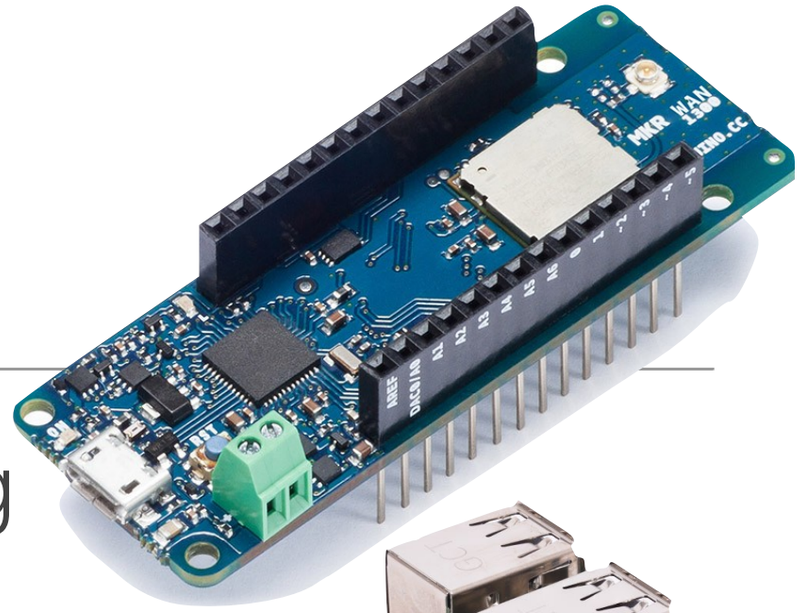
Note 音	Just intonation 純律	Pythagorean 五度相生律	Equal temperament 十二平均律
C	1	1	1
D♭	1.06̇	1.053497942386831 2	1.059463094359295 3
D	1.125	1.125	1.122462048309373
E♭	1.2	1.1̇85̇	1.189207115002721
E	1.25	1.265625	1.259921049894873 2
F	1.3̇	1.3̇	1.334839854170034 4
G♭	1.40625	1.404663923182441 7	1.414213562373095 1
G	1.5	1.5	1.498307076876681 5
A♭	1.6	1.5̇80246913̇	1.587401051968199 4
A	1.6̇	1.6875	1.681792830507429
B♭	1.7̇	1.7̇	1.781797436280678 5
B	1.875	1.898437 5	1.887748625363386 8

How do they sound?

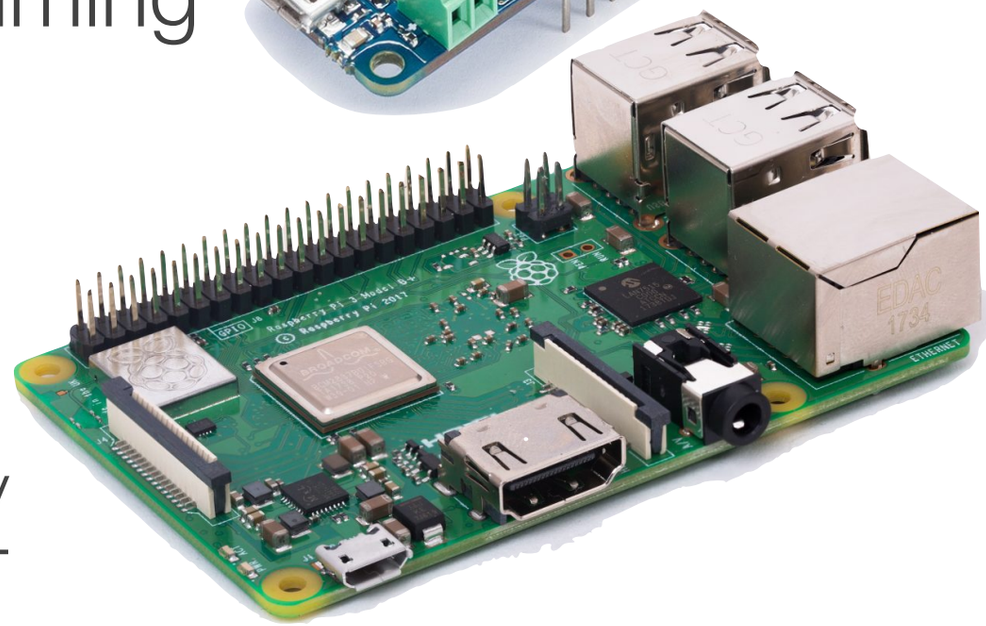
它們聽來怎樣？

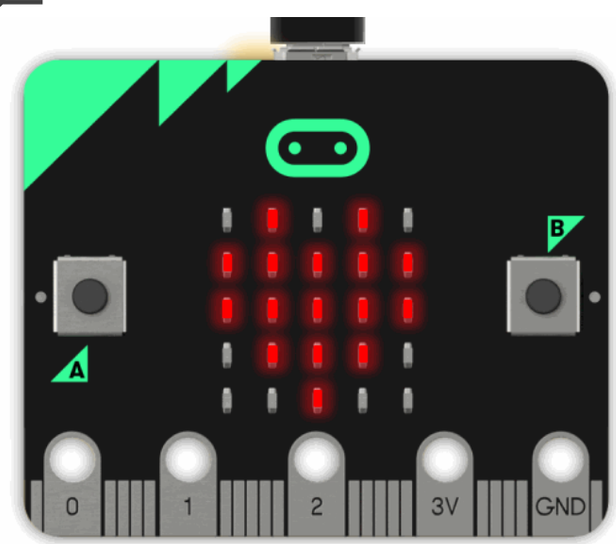
Let's synthesise the sounds
using a credit card-sized computer
and listen!
利用卡片式電腦合成聲音來聽聽吧！

Credit-card sized computers
卡片式電腦



- Low cost, small, portable, programming
  便宜、小巧、易攜、可編寫程式
- Examples 例子：
  - Arduino https://www.arduino.cc/
  - Raspberry Pi https://www.raspberrypi.org/
  - BBC micro:bit https://www.microbit.org/





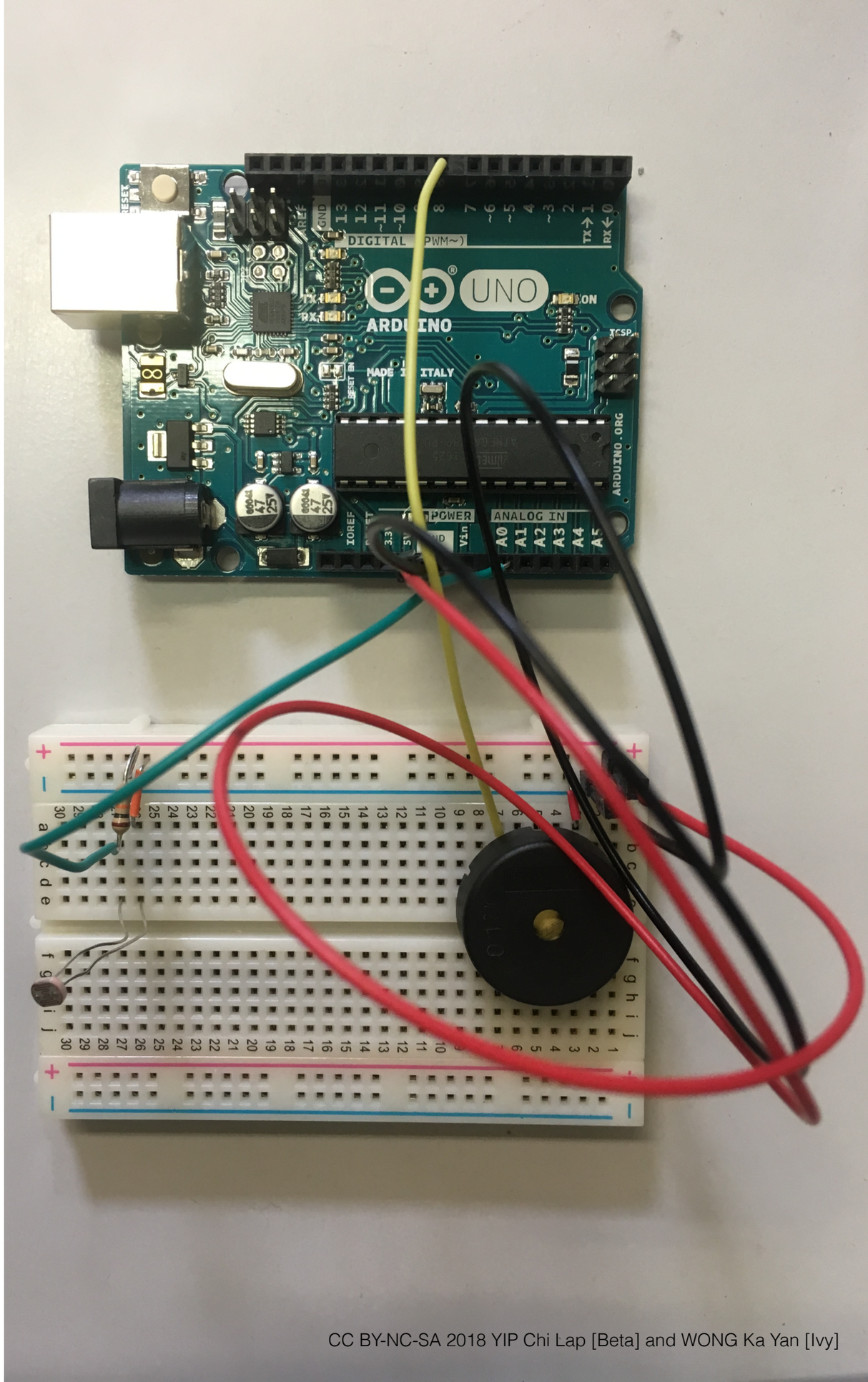
Make sound!
製造聲音！

- ✦ Arudino: use advanced I/O API calls
  利用高階輸入輸出程式接口

  - ❖ `tone(pin, frequency)`
  - ❖ `tone(pin, frequency, duration)`
  - ❖ `noTone(pin)`
  - ❖ https://www.arduino.cc/reference/en/

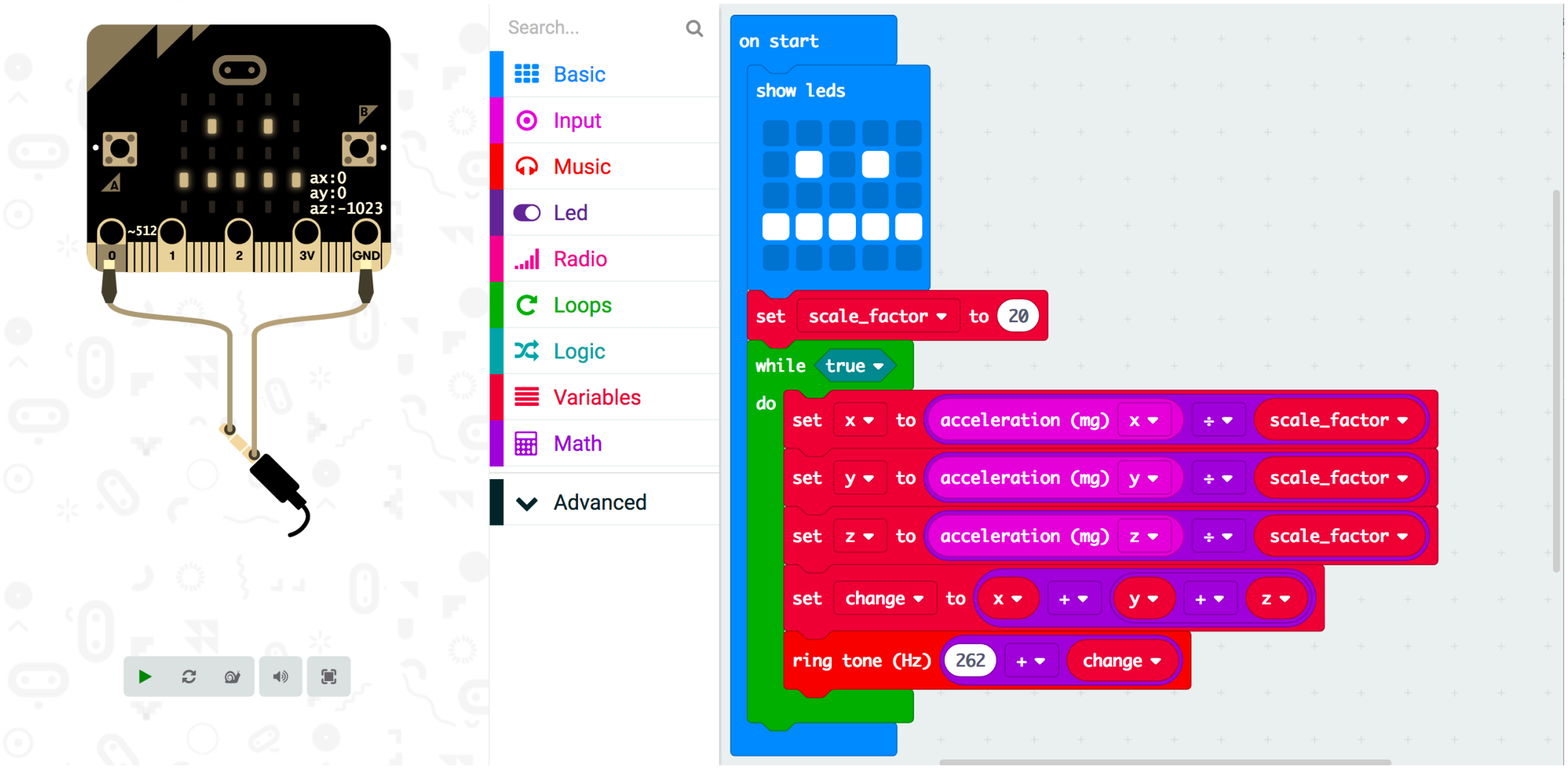
Arduino light-controlled tone generator
Arduino 光控音頻產生器

```
int sensorValue;
int sensorLow = 1023;
int sensorHigh = 0;

const int ledPin = 13;

void setup() {
  pinMode(ledPin, OUTPUT);
  digitalWrite(ledPin, HIGH);

  while(millis()<5000) {
    sensorValue = analogRead(A0);
    if (sensorValue>sensorHigh) {
      sensorHigh = sensorValue;
    }
    if (sensorValue < sensorLow) {
      sensorLow = sensorValue;
    }
  }
  digitalWrite(ledPin, LOW);
}

void loop() {
  sensorValue = analogRead(A0);
  int pitch = map(sensorValue,sensorLow, sensorHigh, 50, 4000);
  tone(8, pitch, 20);
  delay(10);
}
```



Make sound!
製造聲音！

- micro:bit — use the ring tone block or `music.ringTone(freq)` call.
  利用ring tone模組或 `music.ringTone(freq)` 程式接口.



Make sound!
製造聲音！

- ✦ Raspberry Pi — program in Python 寫Python程式
  - ❖ Communicate with Sonic Pi using Open Sound Control (OSC) http://opensoundcontrol.org/
  - ❖ Use library for sound hardware such as Piano HAT https://shop.pimoroni.com/products/piano-hat

PianoHAT on a Raspberry Pi
樹莓派上的 PianoHAT

Sonic Pi

- A free live coding synth for everyone originally designed to support computing and music lessons within schools.
  可即時編碼的合成器，設計為支援在學校的電腦和音樂課。

- Developed by Sam Aaron in the University of Cambridge Computer Lab.
  由劍橋大學電腦中心的 Sam Aaron 及其團隊開發。

- Based on the Ruby programming language. 建基於 Ruby 編程語言。

- Available in Raspberry Pi, OS X, and Windows.
  在樹莓派、OS X，和 Windows 均能使用。

Sonic Pi

- Web site 網站：http://sonic-pi.net/
- Learning resource page 學習資源：https://www.raspberrypi.org/learning/getting-started-with-sonic-pi/

MIDI 樂器數位介面

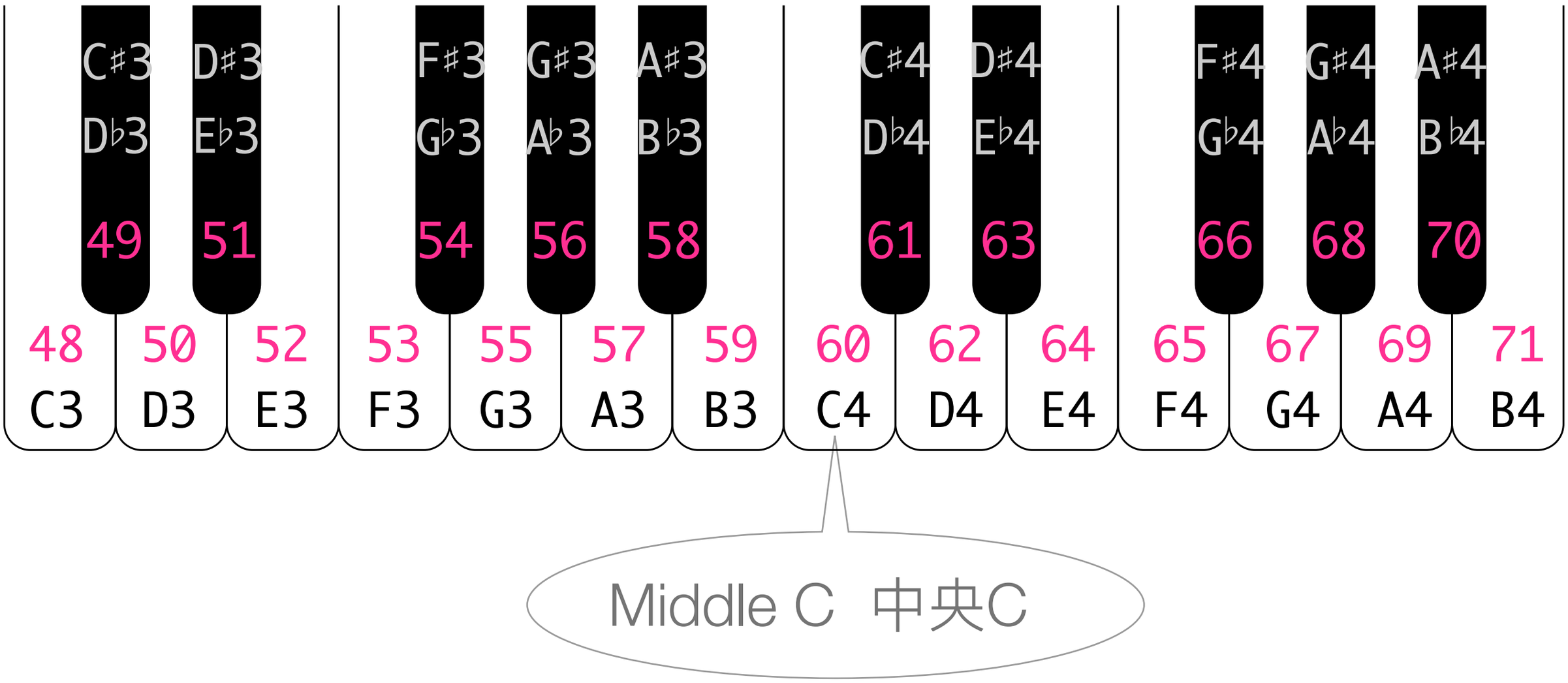
- To process music, computers can use Musical Instrument Digital Interface (MIDI).
  電腦處理音樂，可以用樂器數位介面 (MIDI)。

- Every note has a number after its name to designate the octave it is in, and every note has an unique MIDI note number.
  每個音符的音名後，都有個號碼表明它在哪個八度。而每個音符都有個獨特的 MIDI 音符號碼。

- Middle C is named C4, with a MIDI number 60.
  中央 C 叫 C4，MIDI 音符號碼 60.

- The MIDI number increases by one by going up a semitone.
  向上一個半音，MIDI 音符號碼就會加一。

MIDI note names and numbers
MIDI 音名及音符號碼



MIDI note numbers
MIDI 音符號碼

✦ Range of piano marked in yellow. 黃色底為鋼琴音域。

Octave number	C	C♯ D♭	D	D♯ E♭	E	F	F♯ G♭	G	G♯ A♭	A	A♯ B♭	B
-1	0	1	2	3	4	5	6	7	8	9	10	11
0	12	13	14	15	16	17	18	19	20	21	22	23
1	24	25	26	27	28	29	30	31	32	33	34	35
2	36	37	38	39	40	41	42	43	44	45	46	47
3	48	49	50	51	52	53	54	55	56	57	58	59
4	60	61	62	63	64	65	66	67	68	69	70	71
5	72	73	74	75	76	77	78	79	80	81	82	83
6	84	85	86	87	88	89	90	91	92	93	94	95
7	96	97	98	99	100	101	102	103	104	105	106	107
8	108	109	110	111	112	113	114	115	116	117	118	119
9	120	121	122	123	124	125	126	127				

More HATs

- HAT = Hardware Attached on Top
  https://www.raspberrypi.org/blog/introducing-raspberry-pi-hats/

- 3D sense using Skywriter HAT
  https://shop.pimoroni.com/products/skywriter-hat

- Drum HAT
  https://shop.pimoroni.com/products/drum-hat

Demo time!

示範時間！

References
參考資料

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- ✦ Gödel, Escher, Bach: An Eternal Golden Braid
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Got questions? 有問題？

https://www.facebook.com/HKUEnggMusic