De Unda Aeris

Of the Wave of the Air · the circle in water, the echo, the pipe and the voice

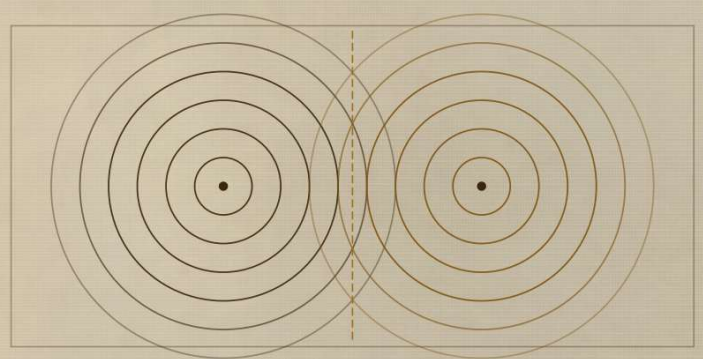
V

1. CIRCULI IN AQUA

Circles in water — the figure of every sound

Throw a stone into still water and rings go out. Throw two stones and each set of rings passes through the other unhurt, so that where the crests meet the water stands high and where crest meets hollow the water lies flat. Neither wave carries the water away; only the form travels. So it is with sound: the air is not blown from the bell to the ear, but the shape of a pushing runs through it, and the air returns to its place.

Coniectura: therefore two voices are not mixed as two wines are mixed. They lie one upon the other and may be taken apart again by an attentive ear — which is why we can follow one singer in a choir of thirty, though we cannot find one wine in a cup of thirty.



upon this line the two waves always agree

Fig. 1. Two stones in one basin. Where the rings cross, count the crossings: they lie upon curves, and the middle line is straight.

2. DE ECHO

Of the echo, and the measuring of a valley by a shout

Sound strikes a wall and returns by the same law as light strikes a mirror: the angle of coming equals the angle of going. Shout across a valley, count the beats of your plumb until the answer arrives, halve them, and you have the distance — for sound goes some 340 metres in one second, which I have taken by watching a distant gun and hearing it after.

$$d = c \cdot t / 2 \quad \cdot \quad c \approx 340 \text{ m/s}$$

two beats of the andante thread → 340 metres to the cliff

Coniectura: light comes before sound — the flash before the report, the lightning before the thunder — therefore light is quicker, and perhaps so quick that it takes no time at all. I doubt the last; nothing in nature is instant.

3. DE SONO SUB AQUA

Of sound beneath the water, and the listening tube

Put your ear to a long tube of tin whose end is under the water and you will hear a boat rowing at a distance at which the eye finds nothing. Sound travels in water faster and further than in air, for water will not be squeezed and passes the push along at once. In wood it is faster still along the grain than across it, which the maker knows in his hands before he knows it in numbers.

MEDIUM	CELERITAS	RATIO
Aer *air*	340 m/s	1.0
Aqua *water*	1480	4.4
Lignum, per fibram	4400	12.9
Lignum, trans fibram	1200	3.5
Ferrum *iron*	5100	15.0

Spruce passes sound along its grain near four times faster than across it, and this alone decides where the bars must lie in a belly: along the grain the sound is already fast, and the bar is set across to hurry the slow direction. *Coniectura: the violin is not a box that holds sound. It is a device for making one speed out of two.*

4. DE REFRACTIONE SONI

Of the bending of sound, and why the far bell moves about

A bell across the water is loud at dawn and faint at noon, though the distance does not change. The cause is the air itself: cold air lies low at dawn and passes the sound more slowly than the warm above, and the ray, entering the slower layer, bends downward and is carried along the surface as light is bent in a glass of water. At noon the ground is hot, the ray bends upward, and the sound goes over the listener's head.

Wind does the same by simple carriage: downwind the ray is bent toward the ground and the bell is heard at a league; upwind it is lifted and lost at a quarter of that. *Coniectura: therefore a man who wishes to be heard in the open should speak at dawn, downwind, over water. I have watched the preachers and they know this without knowing it, which is the usual condition of useful knowledge.*

5. TABULA FISTULARUM

Table of open pipes, their length and their voice

VOX	FISTULA	REDIT/SEC	RATIO
C *bassus*	2600 mm	65.4	1:1
G	1733 mm	98.0	3:2
c	1300 mm	130.8	2:1
e	1040 mm	163.5	5:2
g	867 mm	196.0	3:1
c′	650 mm	261.6	4:1
c″	325 mm	523.3	8:1

The open pipe holds half a wave; therefore its voice is the speed of sound divided by twice its length. A pipe stopped at one end sounds an octave lower on the same length, holding a quarter wave — which is why the organ builder buys half the tin for the same bass.

$$n = c / 2L \quad \cdot \quad n_{clausa} = c / 4L$$

open and stopped pipes; L in metres, c the speed of sound

6. DE VOCE HUMANA

Of the human voice, dissected

I have opened the throat and found no strings, but two lips of gristle which the breath sets trembling, and above them a chamber whose shape the tongue alters. Thus the voice is a pipe of changing form: the trembling gives the pitch, the chamber gives the word. Sing and speak at once and you prove it — the note holds while the vowels walk.

Coniectura: a bellows, two leaves of leather and a pipe of wax that a hand may squeeze would speak, if the hand were patient. I have made the bellows and the leaves. The wax defeats me; the tongue is the most cunning muscle in the body and does in an instant what my model does in a minute.

7. DE VOCALIBUS

Of the vowels, and the two chambers of the mouth

Whisper each vowel without voice and listen to the hiss: each has its own pitch, and the pitches do not walk in one line but in two. As the tongue rises the one climbs and the other falls, so that A stands with both together and I stands with them furthest apart. I have set them against the pipes to name them.

VOX	LINGUA	PRIMA	SECUNDA
A	low, flat	730	1090
E	middle	530	1840
I	high, forward	270	2290
O	low, rounded	570	840
U	high, rounded	300	870

The numbers are returns in the second, taken by matching each hiss against a stopped pipe until the two agree. *Coniectura: a vowel is a chord of two voices which the mouth plays with its own hollows while the throat holds a third beneath. Speech is therefore already music in three parts, and singing is only speech that has agreed to keep the bass still.*

8. DE RESONANTIA

Of sympathy between bodies, which is the strangest thing on this leaf

Sing into a lute laid upon the table and the string of that same note will sound of itself, untouched, while its neighbours stay dumb. Set two glasses of equal water side by side, strike one, and the other hums. The push in the air is the same for all of them; only the one that already knows the number takes it up.

CORPUS	EXCITATUM	VIS
Chorda eadem *unison*	strongly	1.00
Octava	clearly	0.42
Diapente	faintly	0.18
Ditonus	barely	0.07
Semitonium	not at all	0.00

The semitone, which stands nearest of all, answers least: a body will not be moved by a number close to its own, only by its own or the simple multiples of it. *Coniectura: here is the whole doctrine of the codex in one experiment. Nature does not reward similarity; she rewards exact proportion, and she is deaf to everything else. I would have this trial shown to any man who asks why I spend my evenings counting instead of painting.*

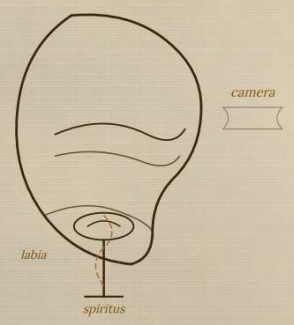


Fig. 2. Section of the throat and the mouth, drawn from a dissection at Santa Maria Nuova: the two lips below, the vaulted chamber above.

AD MARGINEM

In the margin, beside the rings

L'onda fugge, l'acqua resta

The wave flees, the water stays. *The finest sentence on this leaf, and he wrote it about a duck.*

DE CONSONANTIA

Why the ear counts crossings

RATIO	AGREE IN	JUDGMENT
2:1	2 returns	sweetest
3:2	6	sweet
4:3	12	firm
5:4	20	soft
45:32	1440	the devil

The tritone waits fourteen hundred returns to close its pattern; the ear, which will not wait so long, calls it restless and demands it be resolved. *Coniectura: dissonance is not ugliness but impatience.*

VASA SONANTIA

Vessels and pipes, with the note each gives

VAS	LONGITUDO	VOX
Pipe, open	600 mm	ground
Pipe, stopped	300	same
Pipe, open	300	octave
Jar, half full	—	fourth
Jar, brim full	—	tenth
Bell, bronze	—	fifth †

A stopped pipe of half the length gives the same voice as an open pipe of the whole: the air within is folded back upon itself, as light in a mirror.

ECHO MENSURATA

Delay of the returning voice, in beats of the thread

LOCUS	PASSUS	ICTUS
Cloister wall	60	½
Across the moat	120	1
Rock at Vaprio	300	2½
Valley, far side	700	6
Gun, half league	1500	13

The voice goes out and comes back in a time proportional to the road it travels, so the road may be measured by the ear alone. *Coniectura:* the same rule will give the height of a cloud.

VOX HUMANA

Compass of voices, measured on the canon

VOX	LONGITUDO	AMBITUS
Bassus	1200 mm	xii
Tenor	900	xiii
Altus	720	xii
Puer	600	xv

«The air is full of infinite straight lines and radiants intercrossing without displacing one another.»