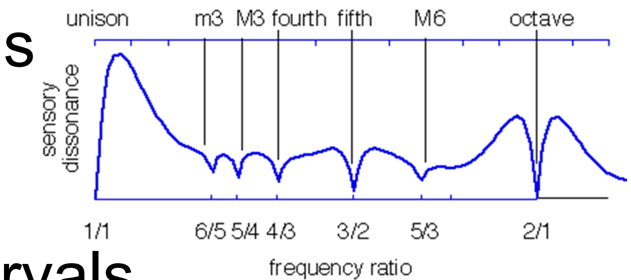
Physics 1240: Sound and Music

<u>Today (7/19/19)</u>: Music: Temperaments, Non-Western Scales

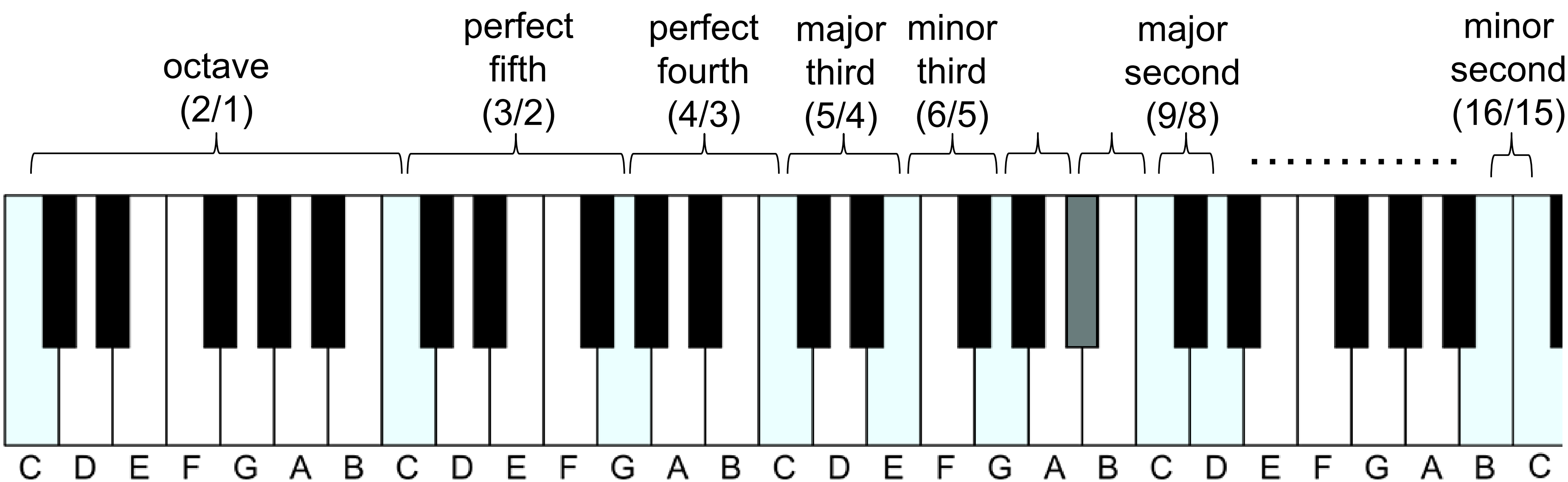
<u>Next time</u>: Fourier Synthesis, Sound Envelopes

Review

- Dissonance: harsh sound when 2 tones (or upper harmonics) produce beats within the same critical band
- Consonance: Pythagorean hypothesis



- Harmonic series → Pythagorean intervals



BA

Clicker Question 9.1

If two tones of different frequencies are sounded together, which ratio of frequencies would lead to the most dissonant sound?

A) 1/1
B) 2/1
C) $\sqrt{2}/1$
D) 1.5/1
E) 9/8

BA

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 BA

Clicker Question 9.2

What is the musical interval between the second and third harmonics of a tone?

A) octave
B) tritone
C) perfect fifth
D) perfect fourth
E) major third

BA

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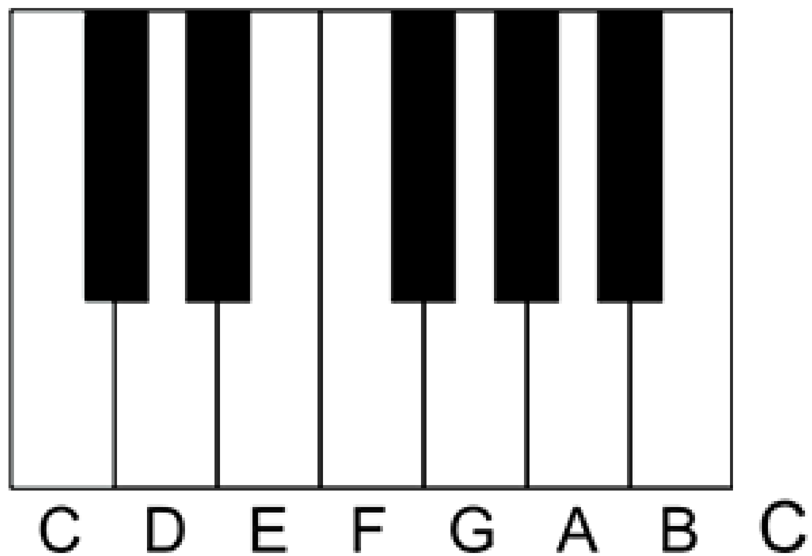
Scale: Just Tuning

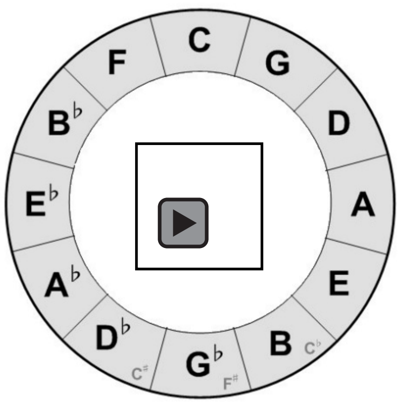
- Assign frequencies to each note ("tuning" the piano) to form a scale
- Based on lowest integer frequency ratios

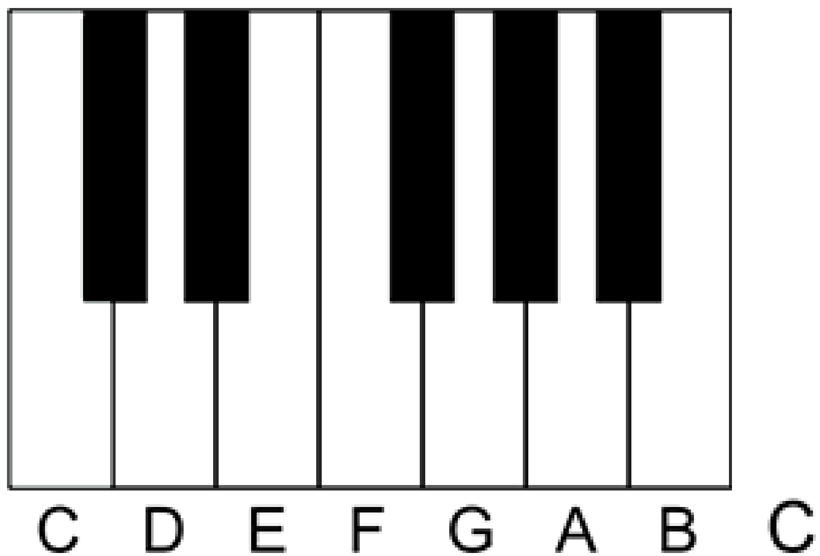


Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{5}{4}$ $\frac{4}{3}$ $\frac{3}{2}$ $\frac{5}{3}$ $\frac{15}{8}$ $\frac{2}{1}$

Scale: Just Tuning

- Benefits: sounds pure
- Drawbacks: only works in one key (not all fifths are perfect 3/2 ratios)





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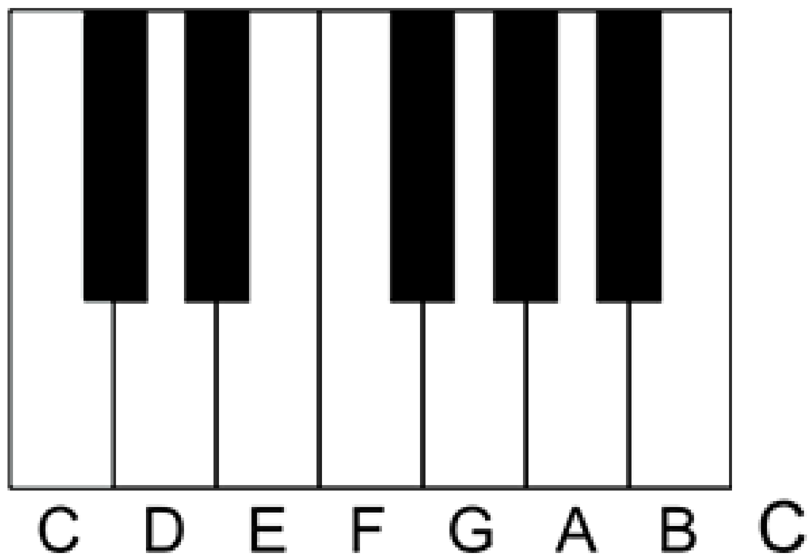
Scale: Pythagorean Tuning

- Goal: make all the perfect fifths within the scale pure (3/2)

D: up two perfect fifths and down an octave: $\left(\frac{3}{2}\right)^2 \times \left(\frac{1}{2}\right) = \frac{9}{8}$

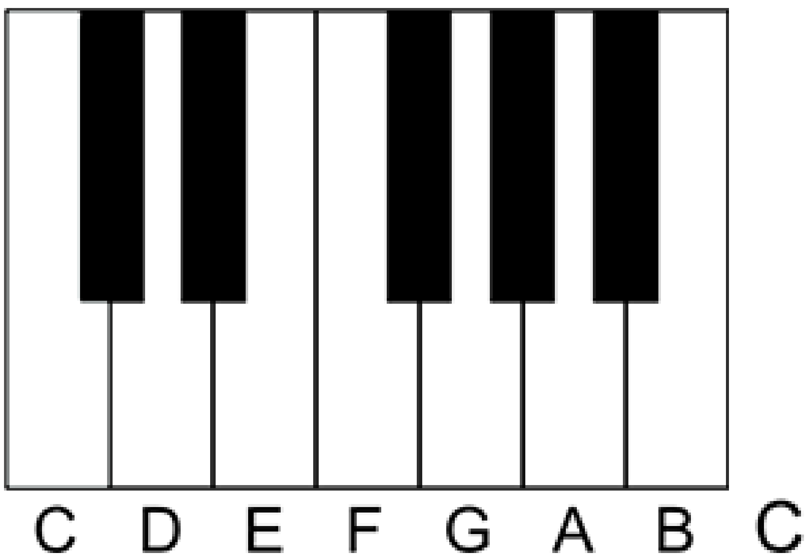


Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{3}{2}$

Scale: Pythagorean Tuning

- Goal: make all the perfect fifths within the scale pure (3/2)

A: up three perfect fifths and down an octave: $\left(\frac{3}{2}\right)^3 \times \left(\frac{1}{2}\right) = \frac{27}{16}$

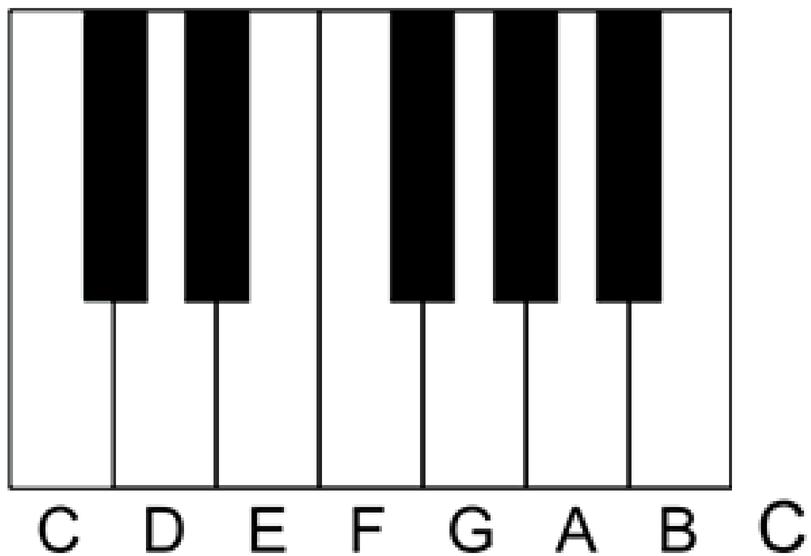


Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{3}{2}$ $\frac{27}{16}$

Scale: Pythagorean Tuning

- Goal: make all the perfect fifths within the scale pure (3/2)

E: up four perfect fifths and down two octaves: $\left(\frac{3}{2}\right)^4 \times \left(\frac{1}{2}\right)^2 = \frac{81}{64}$

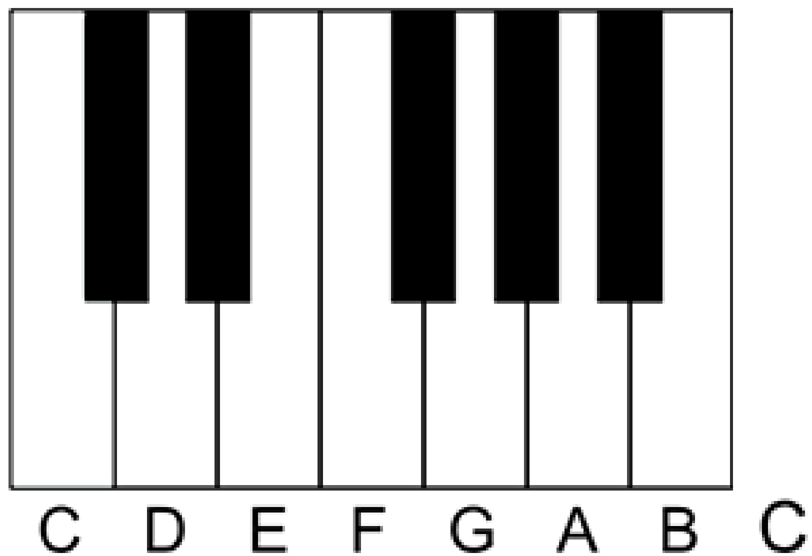


Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{81}{64}$ $\frac{3}{2}$ $\frac{27}{16}$

Scale: Pythagorean Tuning

- Goal: make all the perfect fifths within the scale pure (3/2)

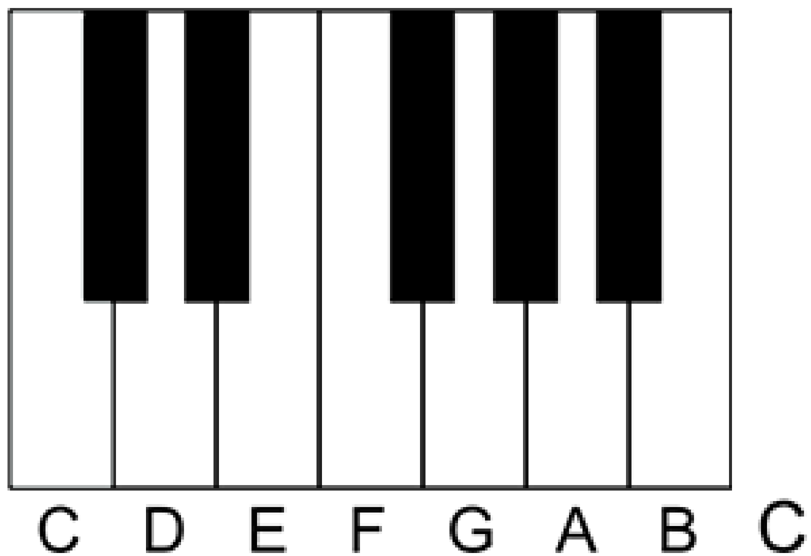
B: up five perfect fifths and down two octaves: $\left(\frac{3}{2}\right)^5 \times \left(\frac{1}{2}\right)^2 = \frac{243}{128}$



Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{81}{64}$ $\frac{3}{2}$ $\frac{27}{16}$ $\frac{243}{128}$

Scale: Pythagorean Tuning

- Goal: make all the perfect fifths within the scale pure (3/2)
- Problem: Pythagorean comma



Ratio to C: $\frac{1}{1}$ $\frac{9}{8}$ $\frac{81}{64}$ $\frac{4}{3}$ $\frac{3}{2}$ $\frac{27}{16}$ $\frac{243}{128}$ $\frac{2.03}{1}$

Scale: Equal Temperament

- Solution: temper the fifths (split the leftover frequency among other intervals to make them each slightly out of tune)

- Equal temperament:
  - All 12 half step intervals are the same frequency ratio
  - each half step is a factor of $\sqrt[12]{2} = 2^{\frac{1}{12}} \approx 1.05945$
  - Anything can be played in any key without going out of tune (since everything is already "equally out of tune")


BA

Clicker Question 9.3

In an equal-tempered 12-note scale, what is the frequency ratio corresponding to a major third?

A) 5/4
B) 81/64
C) $(2^{\frac{1}{12}})^3 \approx 1.189$
D) $(2^{\frac{1}{12}})^4 \approx 1.260$
E) 12/4

BA

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Scale: Equal Temperament

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Interval	Equal Temperament Frequency Ratio		Approximate Difference	Harmonic Series Frequency Ratio	
Unison	$(\sqrt[12]{2})^0$ ≃	1.0000	0.0	1.0000 ≃	1/1
Minor Second	$(\sqrt[12]{2})^1$ ≃	1.0595	0.0314	1.0909 ≃	12/11
Major Second	$(\sqrt[12]{2})^2$ ≃	1.1225	0.0025	1.1250 ≃	9/8
Minor Third	$(\sqrt[12]{2})^3$ ≃	1.1892	0.0108	1.2000 ≃	6/5
Major Third	$(\sqrt[12]{2})^4$ ≃	1.2599	0.0099	1.2500 ≃	5/4
Perfect Fourth	$(\sqrt[12]{2})^5$ ≃	1.3348	0.0015	1.3333 ≃	4/3
Tritone	$(\sqrt[12]{2})^6$ ≃	1.4142	0.0142	1.4000 ≃	7/5
Perfect Fifth	$(\sqrt[12]{2})^7$ ≃	1.4983	0.0017	1.5000 ≃	3/2
Minor Sixth	$(\sqrt[12]{2})^8$ ≃	1.5874	0.0126	1.6000 ≃	8/5
Major Sixth	$(\sqrt[12]{2})^9$ ≃	1.6818	0.0151	1.6667 ≃	5/3
Minor Seventh	$(\sqrt[12]{2})^{10}$ ≃	1.7818	0.0318	1.7500 ≃	7/4
Major Seventh	$(\sqrt[12]{2})^{11}$ ≃	1.8897	0.0564	1.8333 ≃	11/6
Octave	$(\sqrt[12]{2})^{12}$ ≃	2.0000	0.0	2.0000 ≃	2/1

Scale: Equal Temperament

- each half step is a factor of $\sqrt[12]{2} = 2^{\frac{1}{12}} \approx 1.05945$

- Now a tune can sound alright when played in any key

- Equal temperament didn't take hold until around the time of Mozart – why not sooner?

  - Hard to tune this way with just a tuning fork
  - None of the intervals are purely consonant; they're just "good enough"

But Why 12 Notes?

- Any musical system has to balance two competing ideas:

  1) Minimizing dissonance
  (the more notes, the closer the intervals and the more beats there are)

  2) Giving enough complexity to make it interesting
  (the fewer notes there are, the less ways you can combine them into music)

Systems with < 12 notes

- Pentatonic scale
  - Major pentatonic: black keys on piano
    (e.g. Camptown Races, Mary Had a Little Lamb)
  - Minor pentatonic: simple blues scale
  - Equal-tempered pentatonic:
  - Other:
    - Javanese Gamelan - slendro tuning

Systems with > 12 notes

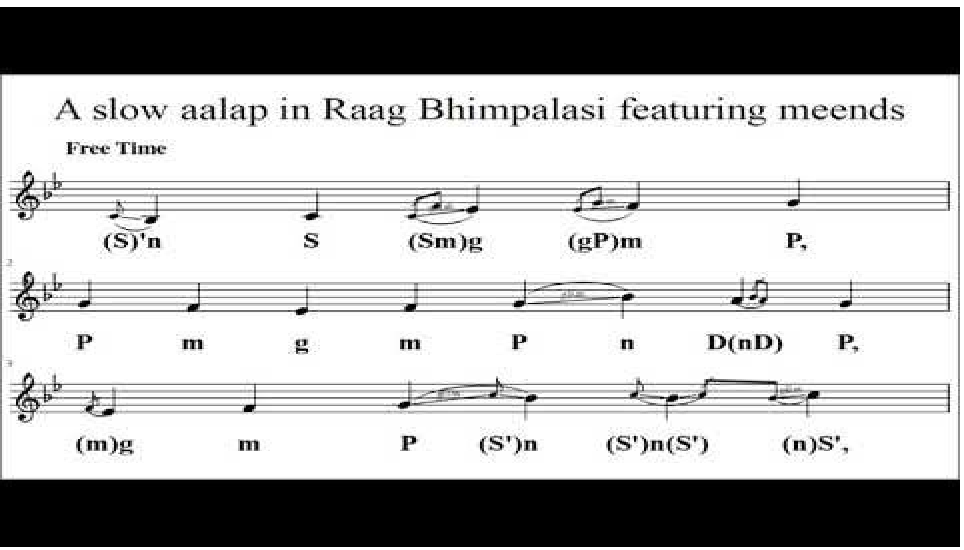
- 43 unequal tones:

- 106 equal tones:

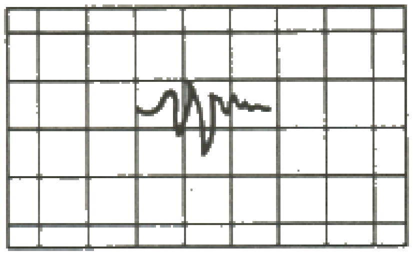
- 24 tones:

Indian Classical Music

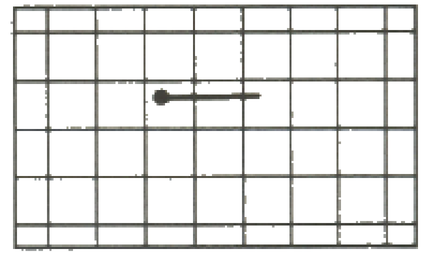
- About 150 different microtonal scales (called “ragas”)
- Sa Re Ga Ma Pa Dha Ni
- No fixed frequencies



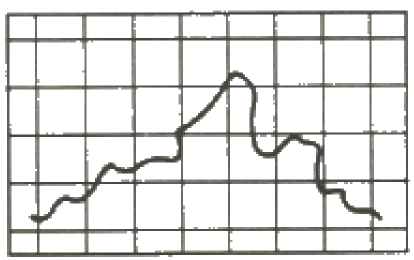
Indian Classical Music



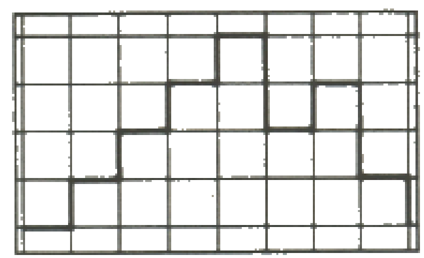
A note in Indian music



A note on the piano



Melodic movement in Indian music



Melodic movement on the piano

Fig. 6–5. Notes and melodic movement, compared with piano.