THE SCIENCE OF MUSIC (HSI2013)
Mid-Term Class Test, Semester 2, 2025/26

This is an open book test. The test is one hour long.

Give your answers to ALL 25 questions on the computer-readable sheet provided, using a soft (2B) pencil to shade the appropriate choice for each question.

1. Which of the following is the most appropriate example of a scientific activity?

   (a) An oboe player performing on a newly invented oboe which can also electronically increase its range downwards to that of a bassoon.

   (b) A trumpet player rehearsing on a trumpet whose tube is curled into a shape like that of a French Horn.

   (c) A timpani player investigating how the material of the drumhead of a timpani affects the sound and loudness of the timpani.

   (d) A physicist playing on xylophones made of different woods whose sound quality varies with each type of wood.

   Answer: (c) The oboe player, trumpet player and physicist are all performing essentially musical activities. The timpani player is the only one performing an essentially scientific activity.

2. Which of the following is the least appropriate example of a technological activity?

   (a) A tuba player inventing a new type of tuba which can also produce sounds which resemble that of a trombone.

   (b) A clarinet player devising a new type of adjustable clarinet mouthpiece which can change the tone colour of a clarinet.

   (c) An organist designing a new type of portable electronic organ whose tone can be electronically altered to also produce the sound of a piano.

   (d) A technician performing on a new type of 'cello whose frequencies can be decreased to also produce double bass sounds.

   Answer: (d) The tuba player, clarinet player and organist are all performing essentially technological activities. The technician is the only one performing an essentially musical activity.

3. Which of the following is the most appropriate example of an object undergoing a vibration?

   (a) A coconut tree swinging from left to right repeatedly during a thunderstorm.

   (b) A scoop of ice cream falling to the floor from an ice cream cone held by a little boy.

   (c) A piece of ice sliding to a stop on a dining table.

   (d) A little girl's head nodding once during a lesson in her Primary One class in school.

   Answer: (a) The piece of ice, scoop of ice cream and little girl's head are each undergoing a single motion and hence not undergoing a vibration. Only the coconut tree is undergoing a repeated movement and is therefore undergoing a vibration.

4. Two flagpoles next to each other are swaying repeatedly from side to side during a strong wind. The shorter flagpole undergoes 6 complete cycles in the same time period during which the longer flagpole undergoes 5 complete cycles. If the longer flagpole undergoes 4 complete cycles in 5 seconds, what is the time period during which the shorter flagpole would undergo 8 complete cycles?

(a) $\frac{5}{14}$ seconds.

(b) $\frac{25}{24}$ seconds.

(c) $\frac{25}{6}$ seconds.

(d) None of the above.

Answer: (d) The longer flagpole undergoes 4 cycles in 5 seconds, so the time it takes to undergo one cycle is equal to $\frac{5}{4}$ seconds. The longer flagpole thus undergoes 5 cycles in $\frac{5}{4}$ seconds times 5 cycles i.e. $\frac{25}{4}$ seconds. The shorter flagpole undergoes 6 cycles in the same time period, so the duration of each of the shorter flagpole's cycles is equal to $\frac{25}{4}$ seconds divided by 6 i.e. $\frac{25}{24}$ seconds. The shorter flagpole would thus undergo 8 cycles in a duration equal to $\frac{25}{24}$ seconds times 8 i.e. $\frac{25}{3}$ seconds.

5. A furniture designer designs a sideboard, and from the furniture designer's plans, a furniture craftsman builds the actual sideboard. A woman sees the sideboard in a furniture shop and buys it for her family to use. A songwriter composes a song, and from the musical score of the song, a singer performs the song for an appreciative audience during a pop concert at the Esplanade Concert Hall. Which of the following has the same relationship to the songwriter as the furniture craftsman has to the furniture designer?

   (a) The Esplanade Concert Hall.

   (b) The singer.

   (c) The audience.

   (d) The musical score.

   Answer: (b). The furniture craftsman follows the plans of the furniture designer and builds the sideboard which is bought by the woman for her family. The singer reads the musical score of the song composed by the songwriter and performs the song for the audience. Therefore the singer has the same relationship to the songwriter as the furniture craftsman has to the furniture designer.

6. A school choir is rehearsing in the school music room. As the choir starts to sing the National Day song "Stand Up For Singapore", a choir member who is late enters the music room. Which of the following songs should the choir member sing as he enters the music room, if counterpoint is not to be produced by the choir and the choir member who is late?

   (a) "We Will Get There".

   (b) "Stand Up For Singapore".

   (c) "We Are Singapore".

   (d) "Home".

   Answer: (b) Counterpoint is produced when two or more different melodies are sung simultaneously. Therefore the choir member who is late should sing the same song which is being sung by the rest of the choir. Hence the choir member should sing "Stand Up For Singapore".

7. The first item in a Junior College concert you are attending is the college band which registers a reading of 91 dB on a sound level meter which you are carrying. The next item in the concert is a student playing a flute solo. The sound from the flute is 10,000 times less powerful than the sound from the college band. What would be the reading on your sound level meter due to the sound from the flute? (Assume that the sound level meter readings are due only to the performers in the concert.)

(a) 51 dB.
(b) 61 dB.
(c) 71 dB.
(d) None of the above.

Answer: (a) A 10 times decrease in the sound power would result in a decrease of 10 dB in the reading of the sound level meter. A decrease of 10,000 times in the sound power i.e. a decrease of 10 times 10 times 10 times 10 times would thus result in a decrease of 10 dB plus 10 dB plus 10 dB plus 10 dB i.e. 40 dB in the sound level meter reading. Hence the sound level meter reading due to the solo flute would be equal to 91 dB minus 40 dB i.e. 51 dB.

8. During a symphony orchestra concert, a bassoon player plays a note with a frequency of 128 Hz. A piccolo player then plays a note with a frequency of 3,520 Hz. Which of the following best describes the interval between the note played by the bassoon player and the note played by the piccolo player?

   (a) Greater than 2 complete octaves but less than 3 complete octaves.
   (b) Greater than 3 complete octaves but less than 4 complete octaves.
   (c) Greater than 4 complete octaves but less than 5 complete octaves.
   (d) Greater than 5 complete octaves but less than 6 complete octaves.

   Answer: (c) Since an octave is an interval with a ratio of $\frac{2}{1}$ i.e. 2, if we go up from a musical note by the interval of an octave, the frequency of the musical note should be multiplied by 2. If we start from the bassoon player's note of 128 Hz, successive multiplications by 2 five times would give us the following frequencies: 128 Hz, 256 Hz, 512 Hz, 1,024 Hz, 2,048 Hz and 4,096 Hz. Therefore the interval from 128 Hz to 3,520 Hz is greater than 4 complete octaves but less than 5 complete octaves.

9. An upright piano has its A4 string tuned to a frequency of 439 Hz, and all its strings are tuned relative to each other as is usual for a piano. A particular note on this piano has a frequency of approximately 1,393.7 Hz. Which of the following is most likely to be the note with this frequency? (Take the ratio of an Equal-tempered semitone to be equal to 1.05946 for your calculations.)

   (a) Fsharp6.
   (b) F6.
   (c) E6.
   (d) Dsharp6.

   Answer: (b) Since the frequency of the A4 string of the upright piano is 439 Hz, its A5 note has a frequency double this i.e. 878 Hz. Going up from this note by eight Equal-tempered semitones, we have to multiply 878 Hz by the ratio of an Equal-tempered semitone i.e. 1.05946 eight times. This gives us a frequency of approximately 1,393.706 Hz. Therefore the note with a frequency of 1,393.7 Hz is most likely to be the note which is eight semitones above A5 i.e. F6.

10. The musical score of a melody for solo trombone begins with a time signature of 34/8. A certain bar of this melody begins with 2 dotted crotchets and ends with 3 crotchets and 8 semiquavers. Of the following combinations of notes, which one would fit exactly into the middle of this bar in agreement with the time signature?

(a) 1 semibreve, 2 dotted crotchets and 3 dotted quavers.

(b) 1 dotted minim, 2 crotchets and 5 dotted quavers.

(c) 2 dotted minims, 2 crotchets and 2 quavers.

(d) 3 dotted crotchets, 2 crotchets and 8 semiquavers.

Answer: (c) The time signature of 34/8 indicates that each bar of the melody must have the duration equivalent of 34 quavers or 68 semiquavers. The beginning of the bar has 2 dotted crotchets equivalent to 12 semiquavers, and the end of the bar has 3 crotchets equivalent to 12 semiquavers and 8 semiquavers, so the bar already has the duration equivalent of 32 semiquavers. Therefore the middle of the bar should be filled with the duration equivalent of 36 semiquavers. 2 dotted minims is equivalent to 24 semiquavers and with 2 crotchets (8 semiquavers) and 2 quavers (4 semiquavers) make up a total of 36 semiquavers.

11. Starting from the note F2 on a piano keyboard, you go upwards by an interval of one and one-third octaves to arrive at a second note. Going downwards from this second note by one and one-sixth octaves, you arrive at a third note. Finally, going upwards from this third note by two and three-quarter octaves, you arrive at the fourth and final note. Which of the following notes is the correct letter name of the fourth note?

(a) E4.

(b) F5.

(c) Fsharp5.

(d) None of the above.

Answer: (d) Going upwards from the starting note F2 by one and one-third octaves means going up by 16 semitones since an octave consists of 12 semitones. Hence the second note is A3. Going down by one and one-sixth octaves or 14 semitones, you arrive at the third note G2. Finally, going up from G2 by two and three-quarter octaves or 33 semitones, you reach the fourth note which is E5.

12. The musical score of a piece for solo clarinet consists of a musical staff starting with a treble clef. A certain bar of this score has its first note written on the second lowest space of the four spaces of the staff, its second note written on the highest line of the five lines of the staff, its third note written on the lowest space of the four spaces of the staff, and its fourth note written on the second lowest line of the five lines of the staff. Which of the following gives the names of these four notes in the correct sequence from the first note to the fourth note?

(a) A4, F5, F4 and G4.

(b) Asharp4, F5, F4 and G4.

(c) A4, E5, F4 and G4.

(d) A4, F5, E4 and G4.

Answer: (a) The treble clef shows that the second lowest line of the staff is the note G4. Therefore the note on the second lowest space of the four spaces of the staff is the note A4, the note on the highest line of the five lines is the note F5, the note on the lowest space of the four spaces is the note F4 and the note on the second lowest line of the five lines is the note G4.

13. A grand piano has its A4 string tuned to a frequency of 442 Hz and all its other strings are tuned relative to each other as is usual for a piano. The A string of a violin is tuned to a frequency of 440 Hz and all its other strings are tuned relative to each other in Just fifths

as is usual for a violin. If a pianist plays a note five semitones below the middle C of this grand piano and a violinist plays the 3rd harmonic of the open D string on this violin, find the interval between these two notes. Open string means that the notes are not played with a finger on the violin's fingerboard, i.e. they are played with the full length of the respective string vibrating. (Take the ratio of an Equal-tempered semitone to be equal to 1.05946 for your calculations.)

(a) 4.470

(b) 4.735.

(c) 5.017.

(d) 5.315.

Answer: (a) The note five semitones below C4 on the piano is the note G3. It is one and one-sixth octaves below its A4 and is therefore given by 442 Hz divided by 2 and then divided by 1.05946 two times, which gives approximately 196.8898 Hz. The open D string of the violin is one Just fifth below its A string. The 3rd harmonic of this string is thus given by 440 Hz divided by $\frac{3}{2}$ and multiplied by 3, i.e. 880 Hz. The interval between the two notes is thus 880 Hz divided by 196.8898 Hz i.e. approximately 4.470.

14. The A string of a 'cello is tuned to a frequency of 220 Hz and all its other strings are tuned relative to each other in Just fifths as is usual for a 'cello. The A string of a bass guitar is tuned to a frequency two octaves below the frequency of the 'cello's A string, and all the bass guitar's strings are tuned in Equal-tempered semitones as is usual for a bass guitar. Of the following, which one is closest to the ratio of the interval between the note from the open G string of the 'cello and the C2 note of the bass guitar? Open string means that the notes are not played with a finger on the 'cello's fingerboard, i.e. they are played with the full length of the respective string vibrating. (Take the ratio of an Equal-tempered semitone to be equal to 1.05946 for your calculations.)

(a) 1.411.

(b) 1.495.

(c) 1.584.

(d) 1.678.

Answer (b) Since the frequency of the A string of the bass guitar is two octaves below 220 Hz or A3, it is the note A1 and its frequency is 55 Hz. Therefore the bass guitar's C2 note which is three Equal-tempered semitones above its A1 note, i.e. 55 Hz multiplied by 1.05946 three times, is approximately 65.4058 Hz. The A string of the 'cello has a frequency of 220 Hz, so the frequency of its G string which is G2 is two Just fifths below the A string. Hence its frequency is equal to 220 Hz divided by $\frac{3}{2}$ two times i.e approximately 97.7778 Hz. The ratio between this G2 note and the bass guitar's C2 note is therefore approximately 97.7778 Hz divided by 65.4058 Hz i.e. approximately 1.495.

15. You start from a first note and go up by an interval of a Pythagorean sixth to arrive at a second note. You then go down from this second note by the interval of an octave and a Just third to arrive at a third note. You then go up from this third note by two octaves and a Pythagorean third to arrive at a fourth note. Finally you go down by a Just seventh to arrive at a fifth note. What is the ratio of the interval between the first note and the fifth note?

(a) $\frac{243}{200}$.

(b) $\frac{729}{200}$.

(c) $\frac{729}{400}$.

(d) None of the above.

Answer: (c) Since the ratio of a Pythagorean sixth is $\frac{27}{16}$, so going up by a Pythagorean sixth means multiplying by $\frac{27}{16}$. The ratio of a Just third is $\frac{5}{4}$, so going down by an octave means dividing by 2 and then going down by a Just third means multiplying by $\frac{4}{5}$. The ratio of a Pythagorean third is $\frac{81}{64}$, so going up by two octaves means multiplying by 2 twice and up by a Pythagorean third means multiplying by $\frac{81}{64}$. The ratio of a Just seventh is $\frac{15}{8}$ so going down by a Just seventh means multiplying by $\frac{8}{15}$. Therefore the ratio of the interval between the first note and the fifth note is given by $\frac{27}{16}$ times $\frac{1}{2}$ times $\frac{4}{5}$ times 4 times $\frac{81}{64}$ times $\frac{8}{15}$. This gives a ratio of $\frac{729}{400}$.

16. A string vibrates at a frequency of 575 Hz when you put your finger at a distance of 24 cm from its nearer end. What is the frequency of the 11th harmonic of the string if the length of the string is 120 cm?

 (a) 1,581.25 Hz.

 (b) 1,380 Hz.

 (c) 1,150 Hz.

 (d) None of the above.

 Answer: (d) Since 24 cm is one-fifth of 120 cm, the string must be vibrating at its 5th harmonic. Therefore the fundamental frequency of the string is given by 575 Hz divided by 5 i.e. 115 Hz. The eleventh harmonic of 115 Hz is equal to 115 Hz times 11 i.e. 1,265 Hz.

17. A 96 cm long string labelled J vibrates at a frequency of 1,200 Hz with m nodes between its two ends (not counting the nodes at both ends). A second string labelled K which is 72 cm long vibrates at a frequency of 1,800 Hz with 9 antinodes between its two ends. String J is then shortened by 25% and vibrates at 1,200 Hz with n nodes between its two ends (not counting the nodes at both ends). Find the ratio m:n. (Assume that strings J and K are identical in all respects except length.)

 (a) 3:2.

 (b) 4:3.

 (c) 7:5.

 (d) None of the above.

 Answer: (c) Since string K has 9 antinodes it is at its 9th harmonic, and its fundamental frequency is given by 1,800 Hz divided by 9 i.e. 200 Hz. Therefore the fundamental frequency of string J is equal to 200 Hz times $\frac{72}{96}$ i.e. 150 Hz. 1,200 Hz divided by 150 Hz is equal to 8, so string J is vibrating at its 8th harmonic and has 8 antinodes or 7 nodes between its two ends. When string J is shortened by 25%, its fundamental frequency will be equal to 150 Hz times $\frac{100}{75}$ i.e. 200 Hz. Since 1,200 Hz divided by 200 Hz is equal to 6, the shortened string J is vibrating at its 6th harmonic and has 6 antinodes or 5 nodes between its two ends. The ratio m:n is therefore equal to 7:5.

18. The distance between a pair of adjacent nodes of a 140 cm long vibrating string is 28 cm. If the string has a fundamental frequency of 160 Hz, calculate the wavelength of the sound wave produced by the vibrating string travelling towards an audience. (Assume that the velocity of sound in air is 330 m/s.)

(a) 34.375 cm.

(b) 41.25 cm.

(c) 51.5625 cm

(d) None of the above.

Answer: (b) Since the length of each vibrating segment of the string is 28 cm, the number of such segments in the string is given by 140 cm divided by 28 cm i.e. 5. The string thus has 5 antinodes and is vibrating at its 5th harmonic, so its frequency is equal to 160 Hz multiplied by 5 i.e. 800 Hz. The wavelength of the sound wave is therefore equal to 330 m/s divided by 800 Hz i.e. 0.4125 m or 41.25 cm.

19. A violinist plays a musical note on her violin which produces a sound wave travelling towards a listener. If the sound wave has a wavelength of exactly 25 cm, which of the following musical notes is most likely to be the note played by the violinist? (Assume that the velocity of sound in air is 330 m/s. Assume also that the notes played by the violin are part of the Just scale and that the A string on the violin is tuned to a frequency of 440 Hz.)

    (a) Dsharp6.

    (b) E6.

    (c) F6.

    (d) None of the above.

    Answer: (b) Since the violin's musical note has a wavelength of 25 cm or 0.25 m in air, its frequency is equal to the speed of sound in air i.e. 330 m/s divided by 0.25 m i.e. 1,320 Hz. The violin's A6 note is two octaves above its A4 note, and is therefore equal to 440 Hz multiplied by 4 i.e. 1,760 Hz. Going down from the A6 note by a Just fourth, we divide 1,760 Hz by the ratio $\frac{4}{3}$ to obtain the frequency 1,320 Hz. Therefore the note with a frequency of 1,320 Hz which is a Just fourth below A6 must be E6, so the note played is the note E6.

20. This is the succession of intervals for a certain Balinese pentatonic scale: semitone, tone, 2 tones, semitone, 2 tones, making up a total of 12 semitones. If we start this scale from the note G5, which of the following is the sequence of notes based on this Balinese pentatonic scale?

    (a) G5, A5, Asharp5, D6, Dsharp6 and G6.

    (b) G5, Gsharp5, B5, D6, Dsharp6 and G6.

    (c) G5, Gsharp5, Asharp5, Dsharp6, E6 and G6.

    (d) G5, Gsharp5, Asharp5, D6, Dsharp6 and G6.

    Answer: (d) Starting from the note G5, the correct succession of intervals i.e. semitone, tone, 2 tones, semitone and 2 tones, is given by the sequence of notes G5, Gsharp5, Asharp5, D6, Dsharp6 and G6.

21. A musical note played by a newly discovered musical instrument has a spectrum which shows that all its harmonics, odd and even, are present up to its 22nd harmonic. A square wave has a spectrum which shows its fundamental frequency and all its harmonics up to its 21st harmonic. The 11th line from the left in the spectrum of the musical instrument's note has a frequency equal to that of the 5th line from the left in the spectrum of the square wave. If the square wave has a fundamental frequency of 99 Hz, what is the frequency of the 15th line from the left in the spectrum of the musical instrument's note? (Assume that the frequencies in each spectrum increase from left to right.)

(a) 1,215 Hz.
(b) 1,053 Hz.
(c) 675 Hz.
(d) None of the above.

Answer: (a) Since the 5th line from the left in the spectrum of the square wave is its 9th harmonic, its frequency is given by 99 Hz times 9 i.e. 891 Hz. The 11th line from the left in the spectrum of the newly discovered instrument's musical note is its 11th harmonic, so its fundamental frequency is given by 891 Hz divided by 11 i.e. 81 Hz. Since the 15th line from the left in the spectrum of the newly discovered instrument's musical note is its 15th harmonic, the frequency of this 15th line is equal to 81 Hz times 15 i.e. 1,215 Hz.

22. An open pipe A is cut into two pipes of equal lengths labelled as B1 and B2. Pipe B2 is then closed at one end so that it becomes a closed pipe. Which of the following statements concerning pipes A, B1 and B2 are correct?
(i) Both the fundamental frequencies of pipes A and B2 are the same.
(ii) The frequency of pipe A when vibrating with 3 nodes between its two ends is the same as that of pipe B2 vibrating with 1 node (not counting the node at one end).
(iii) The wavelength of the sound wave produced by pipe A vibrating with 2 nodes is the same as that produced by pipe B1 vibrating at its fundamental frequency.
(iv) The wavelength of the sound wave produced by pipe A vibrating with 5 antinodes (not counting the antinodes at both ends) is twice that produced by pipe B2 vibrating with 1 antinode (not counting the antinode at one end).

(a) All statements above are correct.
(b) Statements (i), (ii) and (iii) are correct.
(c) Statements (i) and (ii) are correct.
(d) Only statement (i) is correct.

Answer: (b) Let the fundamental frequency of A be f. B1 which is half the length of A will have a fundamental frequency twice that of A, i.e. $2f$. B2 which is a closed pipe will have half the fundamental frequency of B1, i.e. f. When A vibrates with 3 nodes, it is at its third harmonic with frequency $3f$. When B2 vibrates with 1 node, it is at its third harmonic with frequency also $3f$. When A vibrates with 2 nodes, it is at its second harmonic with frequency $2f$ which is the same as the fundamental frequency of B1, so they will produce the same wavelengths of sound. When A vibrates with 5 antinodes, it has 6 nodes and is at its sixth harmonic with frequency $6f$. When B2 vibrates with 1 antinode, it is at its third harmonic with frequency $3f$. Hence the frequency of A vibrating with 5 antinodes is twice that of B2 vibrating with 1 antinode. As frequency is inversely proportional to wavelength, the wavelength of the sound wave from pipe A is therefore half of that from pipe B2.

23. A closed pipe and a string have the same fundamental frequency. The string is then shortened to 60% of its original length. When the shortened string vibrates with 4 nodes (not counting the nodes at both ends), the wavelength of the sound wave it produces is exactly 0.165 metres. What is the frequency produced by the closed pipe when it vibrates with 4 antinodes (not counting the antinode at one end)? (Assume that the velocity of sound in air is 330 m/s.)

(a) 960 Hz.
(b) 1,680 Hz.
(c) 2,640 Hz

(d) None of the above.

Answer: (d) The frequency of the sound wave produced by the shortened string is given by 330 m/s divided by 0.165 m i.e. 2,000 Hz. Since it is vibrating with 4 nodes it has 5 antinodes and thus is at its fifth harmonic. Therefore its fundamental frequency is equal to 2,000 Hz divided by 5 i.e. 400 Hz. The fundamental frequency of the original string is thus equal to 400 Hz multiplied by $\frac{0.6}{1}$ i.e. 240 Hz. The closed pipe is vibrating with 4 antinodes so it will be at its 9th harmonic which is equal to 240 Hz times 9 i.e. 2,160 Hz.

24. A closed pipe labelled P is sliced into 9 short open pipes and one short closed pipe all of equal lengths, and 7 of these short open pipes are joined up to make an open pipe labelled Q. If P vibrates at a fundamental frequency of 210 Hz, what is the wavelength of the sound wave produced by Q when it vibrates with 5 nodes? (Assume that the velocity of sound in air is 330 m/s.)

(a) 5 cm.

(b) 11cm.

(c) 22 cm.

(d) None of the above.

Answer: (b) A closed pipe the same length as Q will have a fundamental frequency given by 210 times $\frac{10}{7}$ Hz i.e. 300 Hz. The open pipe Q thus has a fundamental frequency equal to 300 Hz multiplied by 2 i.e. 600 Hz. When Q vibrates with 5 nodes, it is at its 5th harmonic and its frequency is thus given by 600 Hz times 5 i.e. 3,000 Hz. The wavelength of this sound wave in air is thus equal to 330 m/s divided by 3,000 Hz i.e. 0.11 m or 11 cm.

25. Arrange the following harmonics in order of increasing frequency:
(i) The sixth harmonic frequency of an open pipe E of length p cm.
(ii) The ten harmonic frequency of an open pipe F of length $\frac{8p}{5}$ cm.
(iii) The third harmonic frequency of a closed pipe G of length $\frac{2p}{7}$ cm.
(iv) The fifth harmonic frequency of a closed pipe H of length $\frac{3p}{8}$ cm.

(a) (i), (ii), (iv) and (iii).

(b) (ii), (iv), (i) and (iii).

(c) (iii), (i), (ii) and (iv).

(d) None of the above.

Answer: (c) If f Hz is the fundamental frequency of the open pipe E of length p cm, the sixth harmonic frequency of E is equal to $6f$ Hz. The open pipe F of length $\frac{8p}{5}$ cm has a fundamental frequency equal to f Hz times $\frac{5p}{8p}$ i.e. $\frac{5f}{8}$ Hz, so the tenth harmonic frequency of F is equal to $\frac{5f}{8}$ Hz times 10 i.e. $\frac{50f}{8}$ Hz. An open pipe with the length $\frac{2p}{7}$ cm will have a fundamental frequency given by f Hz times $\frac{7p}{2p}$ i.e. $\frac{7f}{2}$ Hz, and hence the closed pipe G which has the same length of $\frac{2p}{7}$ cm will have a fundamental frequency half of $\frac{7f}{2}$ Hz i.e. $\frac{7f}{4}$ Hz. The third harmonic frequency of G is therefore given by $\frac{7f}{4}$ Hz times 3 i.e. $\frac{21f}{4}$ Hz. The closed pipe H of length $\frac{3p}{8}$ cm has a fundamental frequency given by $\frac{7f}{4}$ Hz times $\frac{2p}{7}$ divided by $\frac{3p}{8}$ i.e. $\frac{4f}{3}$ Hz. The frequency of the fifth harmonic of H is thus equal to $\frac{4f}{3}$ Hz times 5 i.e. $\frac{20f}{3}$ Hz. Hence the harmonics in order of increasing frequency are (iii), (i), (ii) and (iv).

END OF TEST PAPER